Lower 700 MHz Test Report:

Laboratory and Field Testing of LTE Performance near Lower E Block and Channel 51 Broadcast Stations

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Prepared by:

Doug Hyslop doug@WirelessStrategy.com

Paul Kolodzy pkolodzy@Kolodzy.com

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1. Executive Summary

The Federal Communications Commission (FCC) recently issued a Notice of Proposed Rulemaking[1] seeking comment on whether 3GPP Band Class 12 devices operating in the Lower B and C Blocks would experience interference when near DTV Channel 51 or Lower E Block broadcast towers. Lower A Block licensees commissioned laboratory and field testing to determine whether any interference would exist in such a situation that would create an impediment to interoperability.

Laboratory tests performed with AT&T commercial devices validated that no interference would result to Lower B and C Block operations if Band Class 12 devices were employed near Lower E Block and Channel 51 broadcast stations.

As this detailed report covering the results of laboratory and field testing demonstrates, Channel 51 and Lower 700 MHz E Block broadcast transmissions do not pose an interference threat to Lower 700 MHz B and C Block device reception. Field measurements in Atlanta documented the radiofrequency environment around Lower E Block towers, Channel 51 broadcast stations, and commercial LTE base stations. Laboratory tests of commercial AT&T devices used test procedures which effectively removed the narrower Band Class 17 duplexer from consideration, quantifying the performance of the receiver itself. The test results are equally applicable to a Band Class 12 device employing the same receiver but using the wider Band Class 12 duplexer.

The testing also confirmed that commercial devices are designed to far exceed the minimum 3GPP[2] performance criteria in order to ensure compliance with specifications and adequate operation in markets with neighboring LTE systems in place. Band Class 17 devices currently receive and manage interfering signal levels from within the Lower B, C, and Upper C Blocks that are similar in strength to the Lower E Block broadcast signals. Devices designed to tolerate these neighboring LTE base station signals are also capable of handling the Lower E Block signals measured in Atlanta. The narrower Band Class 17 duplexer is not needed; the receiver performance alone is sufficient to protect Lower 700 MHz device reception in the Lower B and C Blocks.

It is also important to distinguish device reception and performance issues affecting interoperability from base station reception and interference issues affecting deployment. Potential interference to Lower A Block base station reception from Channel 51 broadcast stations is a base station interference issue relevant only to Lower A Block deployment in some markets. Similarly, Lower E Block interference to Band Class 12 base station reception may require additional protection or conditions akin to those imposed by the FCC on AT&T's Lower D and E Block licenses. These interference concerns are specific to base station deployment only, and are not in any way related to the topic of Lower 700 MHz device interoperability. Lower A Block system deployment would certainly be aided by

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[1] *Promoting Interoperability in the 700 MHz Commercial Spectrum*, WT Docket No. 12-69, Notice of Proposed Rulemaking, FCC 12-31 (released March 21, 2012).

[2] 3GPP is an international partnership of industry-based telecommunications standards bodies. One of 3GPP's responsibilities is the definition of Long Term Evolution (LTE) specifications. LTE is the dominant 4G wireless broadband technology selected by US 700 MHz Band licensees.

conditions imposed on Channel 51 and the Lower E Block, but such conditions do not impact Lower B and C Block device performance and are not an interoperability prerequisite.

In summary, Band Class 12 devices that comply with 3GPP performance specifications would exhibit normal performance in a commercial system deployment using the Lower B and C Blocks. The use of Band Class 12 devices by AT&T to serve customers in their Lower B and C Blocks would pose no threat to their customer experience. Therefore, interoperability between Lower 700 MHz A, B, and C Blocks is technically feasible.

2. Lower 700 MHz Band Overview

The FCC channel plan for the Lower 700 MHz Band is shown in Figure 2.1. The FCC allocated the 700 MHz blocks under “flexible use” rules, defining power limits and OOBE levels for every block for mobiles, fixed control stations, and base stations. The base station power limits applicable to each block are shown in the figure.

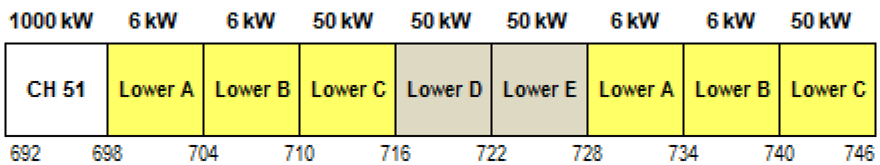

Figure 2.1: Lower 700 MHz Band

In the Lower 700 MHz Band, the FCC paired three 6 MHz blocks of spectrum from 728 to 746 MHz with three similar blocks at 698 to 716 MHz to form the Lower A, B and C Blocks. The FCC allocated the Lower A and B Blocks with a maximum power level for a base station of 1000 W/MHz effective radiated power (ERP)[3], or 6 kW per block. The Lower C Block was allocated with up to 50 kW ERP for each portion of the block to permit broadcast use of the spectrum if desired by the licensee.

The spectrum falling between the Lower A, B and C Blocks consists of two unpaired 6 MHz blocks, D and E, at 716-728 MHz. The FCC allocated the Lower D and E Blocks with a maximum ERP of 50 kW, suitable for broadcast transmissions.

In 2007, AT&T acquired a number of Lower C Block licenses from Aloha Partners for $2.5 billion[4]. The licenses covered a total of 196 million people, bringing a spectrum value of $1.06/MHz-pop[5].

Following their Aloha Partners acquisition, AT&T participated in FCC Auction #73. The FCC auctioned several 700 MHz blocks in 2008: the Lower A, B and E Blocks, and the Upper C Block in the Upper 700 MHz Band. AT&T focused their bidding on the Lower B Block to complement their earlier acquisitions in the Lower C Block.

As of June 2011, AT&T’s Lower 700 MHz spectrum ownership within the continental United States was as shown in Figure 2.2.

[3] ERP is the radiated power with respect to a dipole antenna. EIRP is with respect to an isotropic antenna. ERP is 2.15 dB lower than EIRP.

[4] “AT&T Acquires Wireless Spectrum from Aloha Partners”, AT&T press release, San Antonio, TX, October 9, 2007.

[5] Spectrum valuations are expressed in terms of the license cost in dollars, per MHz within the license, per the number of people covered by the geographic license (pop).

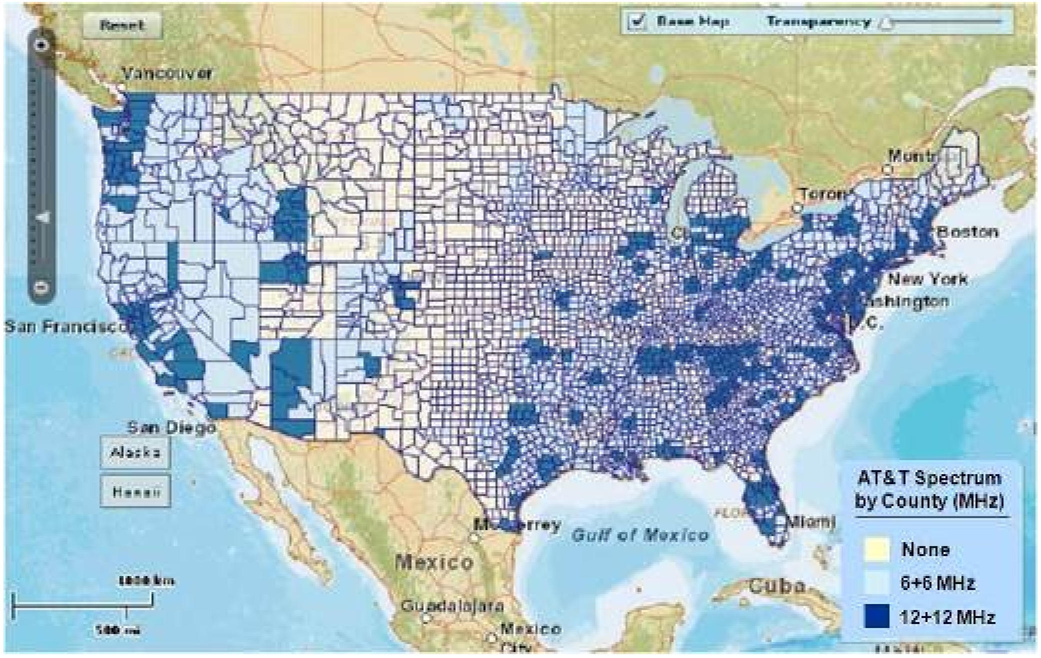

Figure 2.2: AT&T Lower 700 MHz Spectrum Ownership[6]

While AT&T achieved significant Lower 700 MHz ownership in the main population centers, Figure 2.2 also illustrates the large portion of the country where AT&T does not own Lower 700 MHz paired spectrum. In some markets, AT&T owns the Lower B Block, but not Lower C. In other markets, AT&T owns the Lower C Block, but not Lower B. In the markets shaded dark blue, AT&T owns both the Lower B and C Blocks. The yellow shaded portions of the country represent the large geographic areas where AT&T does not own 700 MHz paired spectrum. In these areas, many local and regional operators acquired licenses.

AT&T's fragmented spectrum position requires their LTE system to support more than one channel bandwidth. In markets where AT&T owns only one 6+6 MHz block, AT&T will need to support a 5 MHz LTE channel. In markets where AT&T owns both the Lower B and C Blocks, then AT&T may employ a 10 MHz LTE channel. Since the same equipment is used in different markets, AT&T's devices and base stations support both 5 and 10 MHz LTE channels.

In 2008, shortly after the close of Auction 73, Motorola and AT&T submitted contributions to 3GPP describing potential interference issues in the Lower 700 MHz Band, and recommended the formation of a separate band class. 3GPP approved two LTE band classes for the Lower 700 MHz Band: Band 12, encompassing the Lower A, B and C Blocks, and Band 17, covering only the Lower B and C Blocks.

Theoretical analyses of the 2008 interference claims suggest that Band 17 was not needed for technical reasons[7]. Band Class 12 devices would meet all applicable 3GPP specifications for Lower B and C Block operation.

[6]Figure 2.2 was produced using the Spectrum Dashboard program from the FCC web site, as of June 2011.

The division of the Lower 700 MHz Band into two band classes affected device development. Lower A Block licensees encountered difficulty in acquiring devices given the limited demand for Band Class 12[8]. AT&T's device purchasing power was focused on Band 17. Verizon Wireless, the largest owner of Lower A Block spectrum, focused its initial LTE deployment on Band 13 in the Upper 700 MHz Band.

These ecosystem challenges threaten the viability of Lower A Block systems. Lower A Block operators require access to a wide selection of affordable devices in order to compete with AT&T and Verizon Wireless. This affordable selection would be provided by Lower A Block support in the devices being built for the AT&T LTE deployment.

AT&T, however, defined and selected Band Class 17 based on their interference concerns related to Lower E Block and Channel 51. If AT&T's interference concerns are valid, then the separate band class serves a legitimate technical purpose. On the other hand, if the interference concerns do not prove out in operational systems, then there are no further bars to a harmonization of Lower 700 MHz devices to Band Class 12.

A coalition of Lower A Block licensees commissioned laboratory and field testing to assess Lower B and C Block device performance in the presence of Lower E Block and Channel 51 broadcast transmissions. If the test results validate interference-free operation in the Lower B and C Blocks for Band 12 devices, then Lower 700 MHz device development could shift to Band 12 and deliver ecosystem scale to Lower A Block licensees.

To fully consider the coexistence issues within the Lower 700 MHz Band, the interference scenarios must be assessed from two perspectives. The first perspective is from that of a 3GPP reference receiver[9]. The 2008 3GPP process which resulted in the formation of Band Class 17 was based on this perspective of reference receiver performance.

The second perspective is from that of a commercial device. Commercial devices are designed to well-exceed the minimum performance criteria in order to ensure compliance with the specifications and to ensure adequate operation in a market with neighboring LTE systems in place.

From both perspectives, the test results demonstrate that Band Class 12 devices would comply with 3GPP performance specifications and exhibit normal operation in a commercial system. The use of

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[7] WT Docket No. 06-150, PS Docket No. 06-229, GN Docket No. 09-51 ex parte, Coalition for 4G in America, "Lower 700 MHz Interference Management" by Wireless Strategy, LLC, September 20, 2010.

[8] 3GPP TSG RAN WG5 #46, San Francisco, USA, R5- 100760 Huawei Technologies, "Band 12: Dual Duplexer Approach and Relaxation of Test Frequencies", February 2010. Huawei noted an issue with obtaining Band 12 device components: "One of the challenges we have today is the availability of Band 12 duplexers. RF vendors prefer to re-use Band 17 design to develop a duplexer for Blocks A and B only by tweaking the center frequency. The main driver for this is the small market size of band 12…"

[9] The reference receiver is a hypothetical device representing the lowest level of performance that may still be deemed as complying with the 3GPP specifications.

Band Class 12 devices by AT&T to serve customers in their Lower B and C Blocks would pose no threat to their customer experience.

3. Testing Overview

A coalition of Lower A Block licensees commissioned laboratory and field tests to assess the sufficiency of Band Class 12 for Lower 700 MHz operation.

The interference concerns raised by Band 17 proponents involve Lower B and C Block device reception when near Lower E Block and Channel 51 broadcast towers. The first step in understanding whether interference may occur is to document the radiofrequency (RF) power levels near these broadcast towers in a typical market.

The second step in exploring potential interference is to determine the desired LTE downlink power levels in the market, both in the vicinity of the broadcast towers and when close to a neighboring LTE system's base stations.

The third step in the evaluation is to validate commercial device performance in a controlled laboratory environment. The commercial device performance may then be compared against the RF environment in the operational market to determine whether any interference would exist.

The evaluation will consist of field measurements and lab measurements. The field measurement approach is discussed in section 3.1. The lab testing philosophy and configurations are provided in section 3.2.

3.1. Field Measurement Approach

The ideal test market would contain one or more commercial LTE systems, Lower E Block broadcast sites, and a Channel 51 tower. Since the only operational Lower E Block system in the country was located in Atlanta, this city was the logical choice for field measurements.

The two largest 700 MHz operators have deployed commercial LTE systems in Atlanta, Georgia, as depicted in Figure 3.1. The coverage maps were obtained from each operator's web site and depict 4G coverage in Atlanta as of the time of the field testing in October 2011.

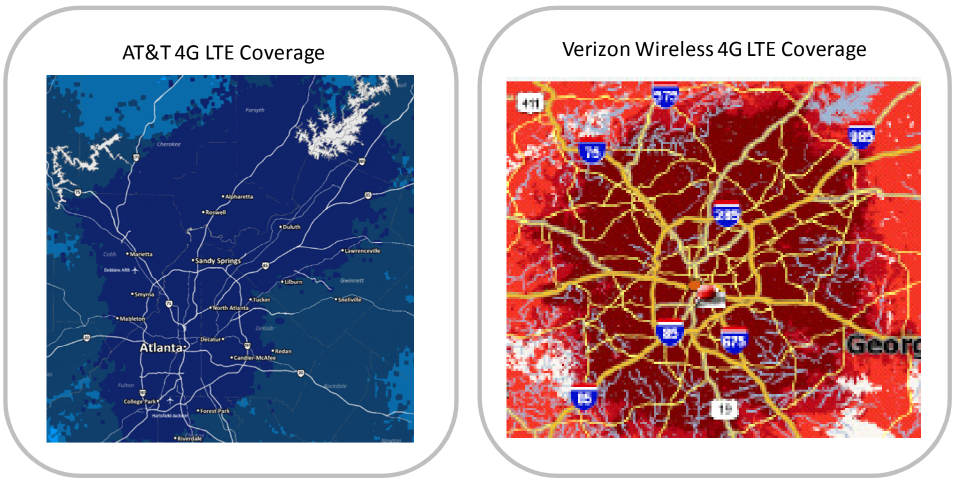


Figure 3.1: AT&T and Verizon Wireless LTE Coverage in Atlanta

The Atlanta market is also served by the Rome DTV 51 tower, located north of Atlanta and providing television service within the greater Atlanta area as depicted in Figure 3.2. The DTV 51 tower is located on a mountaintop with a height above average terrain (HAAT) of 622 meters. The DTV ERP is the maximum allowed power of 1 MW. The tower location was remote with limited accessibility; the closest point of approach without a four-wheel drive vehicle was 2 km.

The DTV site provides a broad television service area – including Atlanta and Rome, Georgia, as well as portions of North Carolina, Tennessee, and Alabama. With such long-range coverage, DTV stations may be located in relatively remote areas in order to increase their transmission height through tall towers or effective use of terrain.

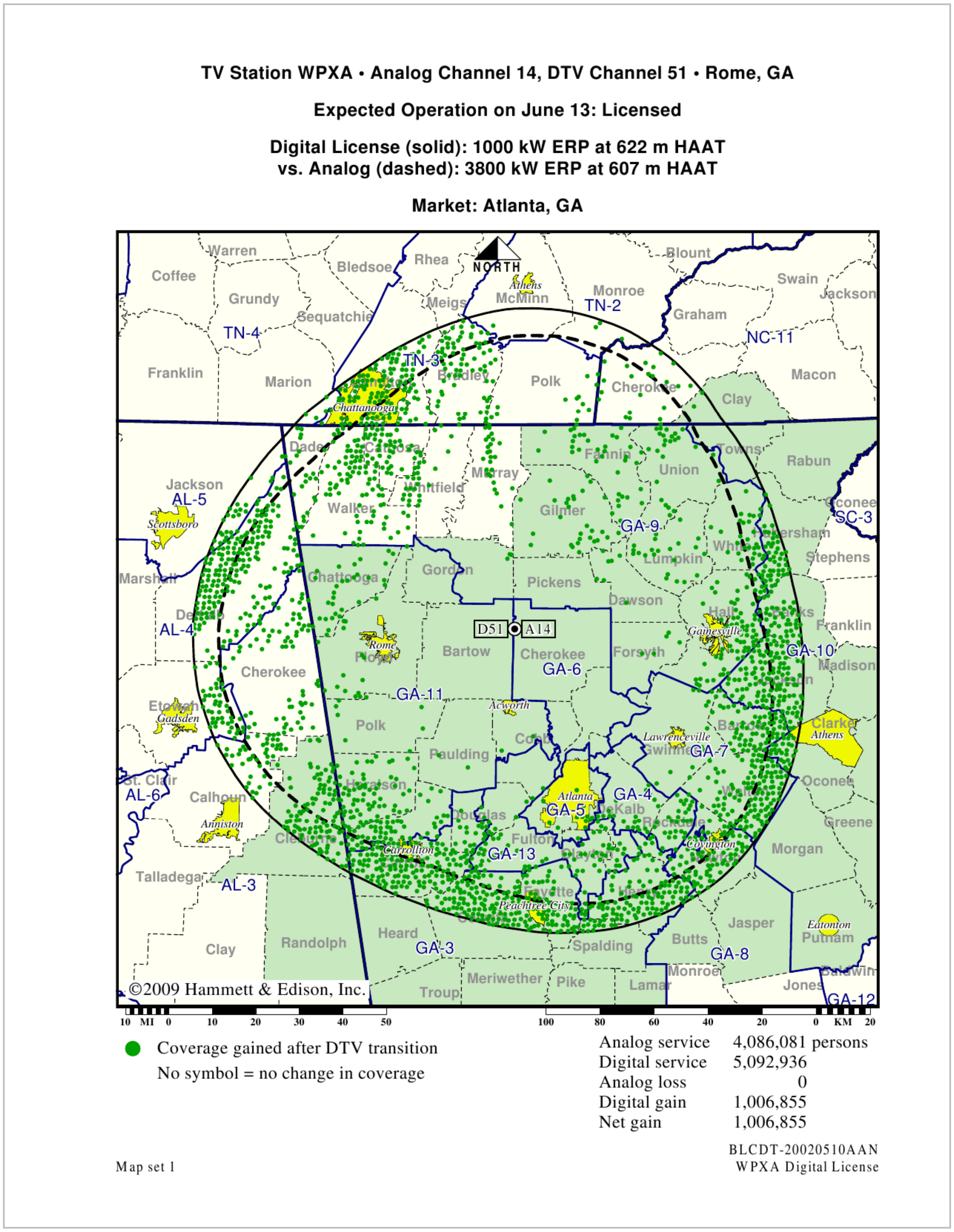


Figure 3.2: WPXA DTV Channel 51 Coverage Map (FCC Media Bureau)

The Atlanta market also hosts the Dish Network E Block video broadcast trial. Dish was operating four broadcast towers covering Atlanta at the time of the testing. The ERP levels for the trial sites are provided in Table 3.1. The E Block towers were transmitting at the maximum allowed ERP of 50 kW, except for the Sweat Mountain site north of the city, which had an equipment issue limiting its output power. We coordinated with the Dish Network engineering team at the start of data collection each day to ensure the test sites were operational and transmitting at full power.

Importantly, Atlanta is the only market in the US where a broadcast video deployment in the 700 MHz band is actively transmitting. Qualcomm's MediaFLO system, which previously had provided mobile video service through over 500 sites nationwide, was de-commissioned in 2010 in preparation for the Lower D and E Block license sale to AT&T.

Channel	City	State	AGL (m)	ERP (kW)	Latitude	Longitude
E	Atlanta	GA	329	50	33.74467	84.359917
E	Sweat Mountain	GA	Mtn	20	34.06625	84.453917
E	Conyers	GA	350	50	33.73944	84.003889
E	Fayetteville	GA	151	50	33.45525	84.409833
DTV 51	Rome	GA	246	1000	34.31333	84.648611
LPTV 47	Norcross	GA	138	12.5	38.91667	84.201944

Table 3.1: Tower Locations in Atlanta

A low-power TV station transmitting on Channel 47 was also measured as part of the test campaign to provide an understanding of the signal levels in the vicinity of Channel 51 LPTV stations.

The DTV, LPTV and Lower E Block site locations are provided in the map in Figure 3.3.

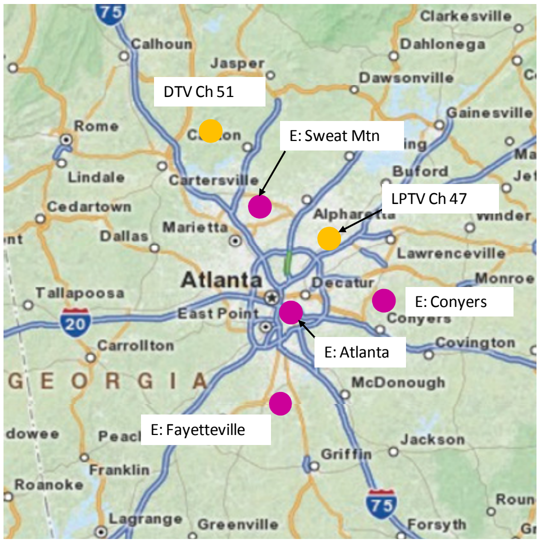


Figure 3.3: Tower Locations in Atlanta

The field measurements were collected with a multi-band antenna mounted on the trunk of the car, connected to a scanning receiver manufactured by Midwest Microwave Solutions, Inc. Position information was provided by a GPS antenna, and measurement data was recorded onto a laptop computer. The test configuration is provided in Figure 3.4.

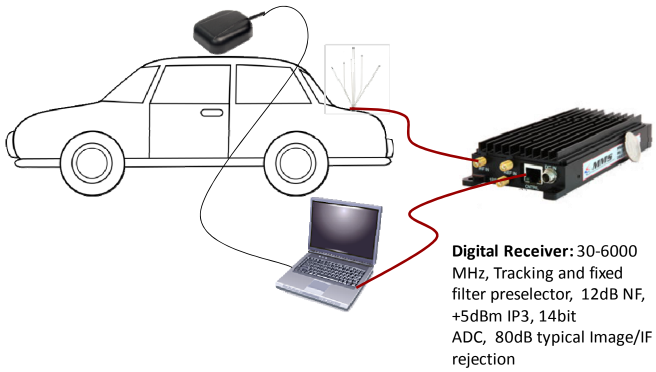


Figure 3.4: Field Measurement Configuration

The test antenna was a Super-M Ultra Mobile antenna model 08-ANT-0860 by MP Antenna, Ltd. The antenna gain at 700 MHz is 2.5 dBi. The antenna was magnetically mounted on the trunk of the car with a ten-ft section of RG58 cable connecting the antenna to the test receiver. The cable and connector losses totaled 2.2 dB. Thus, the received signal levels reported by the receiver are approximately equivalent to the ground-level signal strength (+2.5 dBi antenna gain – 2.2 dB cable/connector losses = +0.3 dB).

The field measurement results are presented in the sections discussing the Lower E Block and Channel 51.

3.2. Laboratory Test Configurations

The laboratory tests were conducted in the AT4 Wireless testing laboratory in Herndon, Virginia in November 2011. The devices under test included the two models of Lower 700 MHz LTE device available for purchase at the time of testing: the AT&T Elevate 4G LTE MiFi modem and the AT&T Momentum 4G LTE USB dongle.

3.2.1 Receiver Blocking Test Configuration

The test configuration for the Receiver Blocking test is provided in Figure 3.5.

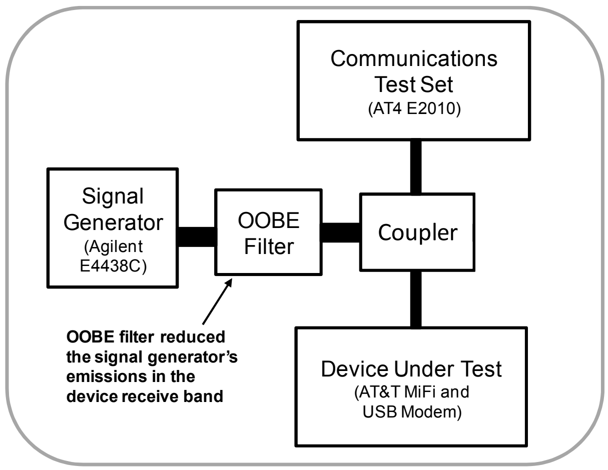


Figure 3.5: Receiver Blocking Test Configuration

The receiver blocking test equipment consisted of a signal generator and an AT4 wireless communications test set to provide the LTE base station signals. The signal generator output was filtered to reduce the out-of-band emissions, ensuring that any degradation in reception was attributable to blocking from the strong interfering signal rather than by out-of-band emissions from the signal generator.

The test approach placed a 5 MHz LTE downlink signal in the Lower C Block (740-746 MHz) with a signal level of -90.3 dBm in 4.5 MHz. Interfering signals were placed in the Lower A and B Blocks, within and adjacent to the passband of the Band 17 device's RF filter. The placement of the interfering and desired signals in relation to the Band 17 duplexer receive filter is illustrated in Figure 3.6.

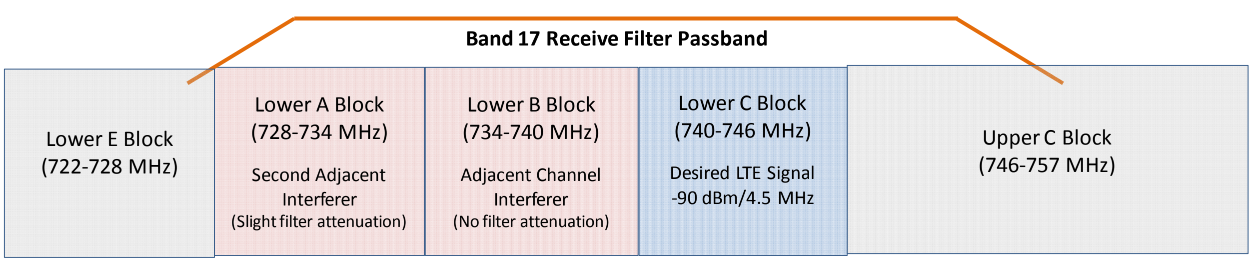


Figure 3.6: Interferer Placement for Receiver Blocking Test

The receiver blocking test configuration effectively removed the device RF filter from consideration. The adjacent channel tests (Lower B to C Block) occur within the passband of the Band 17 filter. In this test, the Band 17 RF filter plays no role in reducing the interferer amplitude; the test result is achieved solely by the receiver components.

The second-adjacent channel tests (Lower A to C Block) occur with the interferer in the adjacent channel to the Band 17 RF filter. Some slight attenuation from the Band 17 filter is present in this test, since the Band 17 filter begins to roll off across the Lower A Block. This second-adjacent channel blocking test is analogous to an E Block interferer adjacent to the Band 12 RF filter. A similar attenuation would be present within the E Block from a Band 12 RF filter. Thus, the Lower A-to-C Block interference test provides identical results to a Lower E-to-B test for a Band 12 device.

The OOBE filter in the blocking test configuration attenuated the signal generator emissions within the Lower C Block (>740 MHz), while passing transmissions below 739 MHz. The OOBE filter response employed in the blocking tests is shown in Figure 3.7.

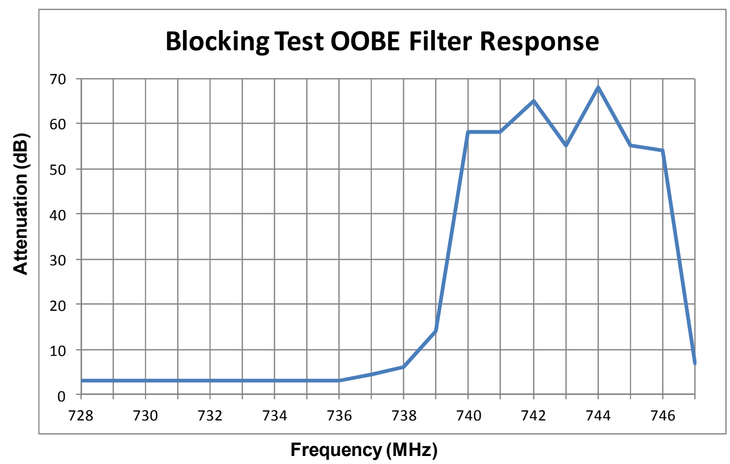


Figure 3.7: OOBE Filter Characteristic

In the receiver blocking test, the interfering signal strength was increased until LTE block errors began to occur. The interfering power level was recorded as the threshold at which degradation from receiver blocking was beginning to occur. Then, the interfering signal was moved lower in frequency and the test was repeated. This approach documented the device susceptibility to blocking as a function of frequency separation.

3.2.2 Reverse PA IM Test Configuration

The device interference mechanism claimed for Channel 51 is reverse power amplifier (PA) intermodulation (IM). The Reverse PA IM device test configuration is shown in Figure 3.8. The test equipment consisted of a signal generator, a spectrum analyzer, an OOBE filter, a Tx band reject filter, and an AT4 wireless communications test set to provide the LTE base station signals.

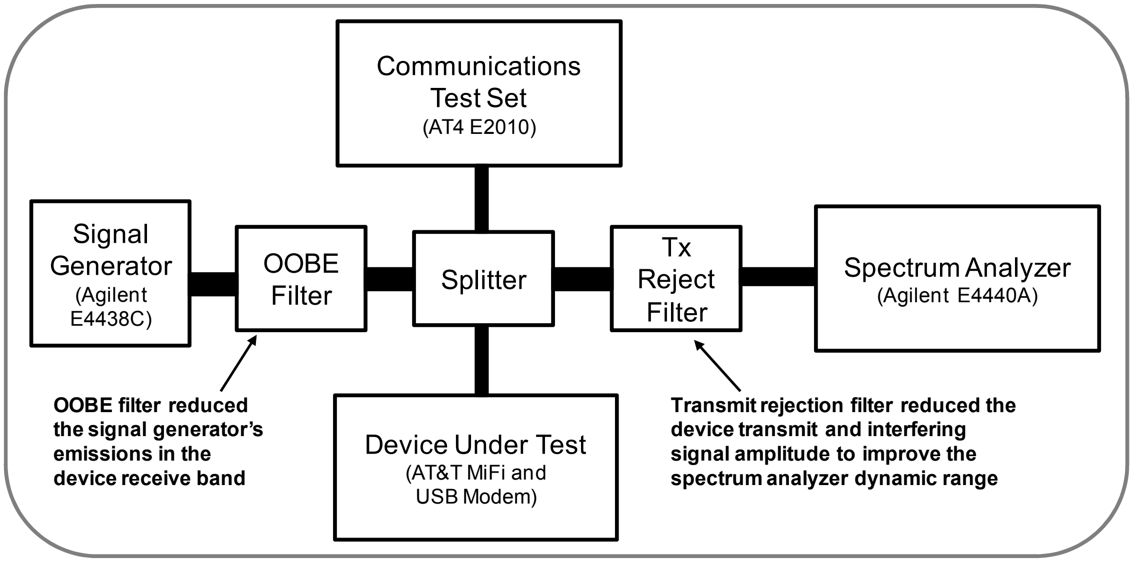
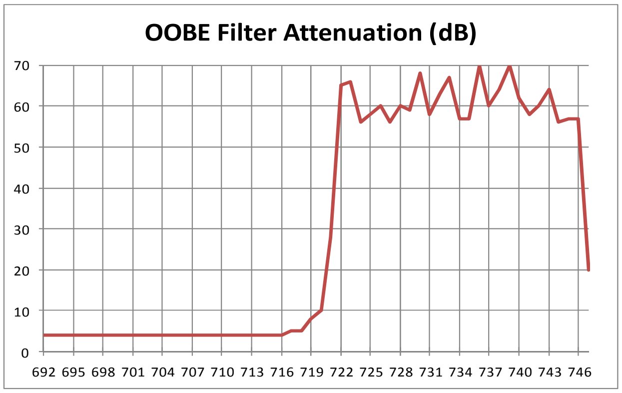


Figure 3.8: Reverse PA IM Test Configuration

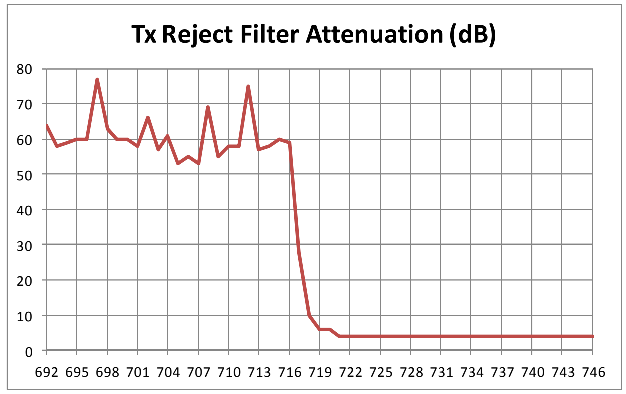
The signal generator produced high power interfering signals with a 6 MHz bandwidth. The out-of-band emission filter reduced the noise produced by the signal generator, which was only 70 dBc without the filter. The intermodulation products were expected to be considerably weaker than this level, thus, the filter was essential to a successful measurement.

Similarly, a rejection filter was placed in front of the signal analyzer to reduce the amplitude of the high-power device transmission and the strong interfering signal at the analyzer. This filter improved the test dynamic range by ensuring the analyzer front end was not overloaded by the test transmissions. With the filter passband covering the device receive frequencies, any intermodulation products passed through the filter with little attenuation and were visible on the spectrum analyzer.

The filter characteristics are provided in Figure 3.9 below.



Model #18181
Microwave Filter Company, Inc.



Model #18182
Microwave Filter Company, Inc.

Figure 3.9: Reverse PA IM Test Filter Characteristics

The reverse PA IM tests were conducted by placing a strong interfering signal within Channel 51 and configuring the UE to transmit at full power within a designated set of resource blocks. By increasing the DTV signal strength sufficiently, intermodulation products were generated and visible on the spectrum analyzer. The IM product amplitude was then applied to third order response formulas to derive the device power amplifier third order output intercept point (OIP3). With the power amplifier's intermodulation response determined, the impact of a Band 12 versus Band 17 filter is readily quantified.

4. Lower E Block

The Band 17 proponents were concerned that Lower E Block broadcast transmissions could present a strong interfering signal at the antenna of a device operating in the Lower B and C Blocks. If the E Block signal was sufficiently strong, the device could experience data errors from receiver blocking. These theoretical claims of device receiver blocking may be explored through laboratory and field measurements.

The field measurements documented the typical RF environment in a commercial LTE network, collecting data for both the AT&T and Verizon Wireless 700 MHz systems in Atlanta.

The field tests also measured signals near Lower E Block broadcast towers operated by Dish Network. The Dish sites follow the profile expected for broadcast towers – employing 50 kW transmitters mounted on tall towers to cover as broad of an area as possible.

The laboratory tests documented the receiver blocking performance for the commercially available AT&T devices. The tests were performed with the interfering signal placed within and adjacent to the Band 17 receive filter passband. This approach isolates the receiver component capabilities from the RF filter capabilities. The test results with the interferer in the Lower B Block purely reflect the receiver component performance. No interference reduction is provided by the Band 17 duplexer. Therefore, the blocking test results are equally applicable to Band 12 and Band 17 devices, and accurately show the device blocking performance within the Lower B and C Blocks in the presence of strong Lower E Block transmissions.

4.1 3GPP UE Blocking Criteria

In their 2008 3GPP contribution[10] introducing Band 17, Motorola described a device blocking concern related to the Lower E Block. Motorola's blocking argument is captured below:

> *"c) As shown in figure 2-1, there may be some impact performance from high broadcast transmission for channel 55/56 for UE supporting Band 12 (A+ B+ C)as since limited RF filtering would be available to provide adequate UE Rx out of band blocking rejection if A block part of the operating band. Again, the magnitude of this problem is a function of the operator's deployment scenario."*

To restate Motorola's concern above, devices closely approaching a high-power Lower D or E Block tower might suffer receiver blocking from the strong signal. As Motorola acknowledged, the likelihood of interference is a function of the operator's deployment scenario.

The 3GPP UE blocking requirements[11] for the Lower 700 MHz Band are summarized in Table 4.1. The blocking signal levels are provided for a desired signal in the Lower B Block, which presents the most stringent blocking requirement for Lower D and E and will be used in the below analysis.

	UE Transmit Band			Tx-Rx Transition Gap		UE Receive Band			
700 MHz Block	A Block	B Block	C Block	D Block	E Block	A Block	B Block	C Block	Upper C
Normal 3GPP Band	-44	-44	-44	-44	-56	ACS	Desired	ACS	-56
Band 12	-15	-15	-15	-30	-56	ACS	Desired	ACS	-56
Band 17	-15	-15	-15	-30	-30	ACS	Desired	ACS	-56

Table 4.1: 3GPP Blocking Criteria for Lower B Block Reception

As seen in Table 4.1, the Lower D Block blocking specification is the same for both Bands 12 and 17. This means that a Band 12 device operating within the minimum 3GPP specifications will perform identically to a Band 17 device in the presence of a Lower D Block interferer. Both Bands 12 and 17 have at least 6 MHz of frequency separation from the Lower D Block, providing sufficient spectral separation for the device receive components and the duplexer filter to attenuate the Lower D Block interferer. The focus for the receiver blocking discussion is therefore the Lower E Block.

The hypothetical 3GPP reference receiver, adhering to the minimum 3GPP specifications, must be capable of receiving its desired signal in the presence of the interfering E Block signals shown in the yellow boxes in Table 4.1. Interfering signals stronger than that shown may degrade the reference receiver performance, causing bit errors or interrupting communications. The Band 12 blocking level of -56 dBm is the in-band blocking (IBB) level for 3GPP reference receivers, and assumes no improvement

[10] 3GPP TSG WG4 Kansas City, USA, R4-081108, "TS36.101 Introduction of Band 15", Motorola, May 2008.

[11] 3GPP TS 36.101 v8.9.0 (2010-03), "User Equipment Radio Transmission and Reception", sections 7.5-7.6.

from a duplexer filter. The Band 17 blocking level of -30 dBm in the Lower E Block assumes duplexer filter rejection given the greater frequency separation from the edge of Band 17 (Lower B Block).

This Lower E Block blocking level is the only difference in the 3GPP performance specifications between Bands 12 and 17. All other specifications (besides frequency range) are identical. Therefore, the entire question of interoperability, from 3GPP's perspective, is solely related to the Lower E Block receiver blocking question.

An equally important observation from Table 4.1 is the identical blocking specifications of Bands 12 and 17 toward the Upper C Block (746-756 MHz). Both band specifications require devices to support an Upper C Block interfering signal level of -56 dBm. Upper C Block signals which are stronger than this level may pose a receiver blocking issue to a 3GPP reference receiver, identical to the Lower E Block blocking situation described by Motorola in 2008.

The blocking signal levels in Table 4.1 are applicable relative to a desired LTE signal level specified by 3GPP. Stronger desired signal levels tolerate stronger interfering signal levels, as indicated by the definition of the adjacent channel selectivity (ACS) test cases by 3GPP[12].

A more convenient way to express the relationship between the desired and interfering signal levels is through the power ratio of the two signals. This acceptable power ratio is referred to as the selectivity of the device receiver. The minimum 3GPP reference receiver selectivity is shown in Table 4.2 below, as derived from the ratio of the ACS and IBB interfering signal levels to the desired signal.

Desired Signal	Interfering Signal	Relationship	3GPP Minimum Selectivity (dB)
Lower A	Lower E	Adjacent Channel	31.5
Lower B	Lower E	Second Adjacent	35
Lower C	Lower E	Third Adjacent	47

Table 4.2: 3GPP Reference Receiver Selectivity (Band Class 12)

As shown in Table 4.2, a Band 12 reference receiver operating in Lower B would tolerate a Lower E signal 35 dB stronger than the desired LTE signal. If the LTE system were operating in the Lower C Block, then a 3GPP reference receiver would perform normally provided that the Lower E Block signal was no more than 47 dB stronger than the LTE signal. These are the important thresholds in evaluating the performance of a 3GPP Band 12 reference receiver in the presence of Lower E Block and neighboring LTE base stations.

[12] 3GPP TS 36.101 v8.9.0 (2010-03), "User Equipment Radio Transmission and Reception", section 7.5 Adjacent Channel Selectivity Test Cases. Levels are defined for interfering signals of -56 dBm and -25 dBm, but the ratio between the desired and interfering signals is the same for each case. This power ratio is the relevant parameter for determining whether interference may exist.

Similar statements hold true for Band 17 devices when closely approaching a Verizon Wireless or Lower A Block base station. A 3GPP reference receiver may experience interference when the VZW signal is more than 31.5 dB stronger than the Lower C Block signal, and more than 35 dB stronger than the Lower B Block signal.

These power ratios define the minimum acceptable performance for a 3GPP reference receiver. The lab and field measurements will be compared against these criteria to determine whether interference might exist.

4.2 Commercial UE Blocking Performance

The goal of the laboratory tests was to quantify Lower B and C Block Band 12 device performance in the presence of a strong Lower E Block interferer. However, no commercial Band 12 devices were available at the time of testing. Since the only difference between a Band 12 and 17 device is the duplexer transmit and receive filters, we adopted a test methodology which removed the filter from consideration.

Commercial AT&T devices were tested in the laboratory to validate their receiver blocking performance. The test configuration, described in section 3.2.1, placed the desired LTE downlink signal in the Lower C Block. The interfering signal was placed adjacent to the desired signal, in the Lower B Block. This interferer placement documented the receiver blocking performance of the Band 17 device *within the filter passband*. By placing the interferer within the Band 17 passband, we negated the role of the duplexer in the blocking tests. The adjacent channel blocking test results are equally applicable to Band 12 or Band 17 devices, reflecting the capabilities of the receiver itself.

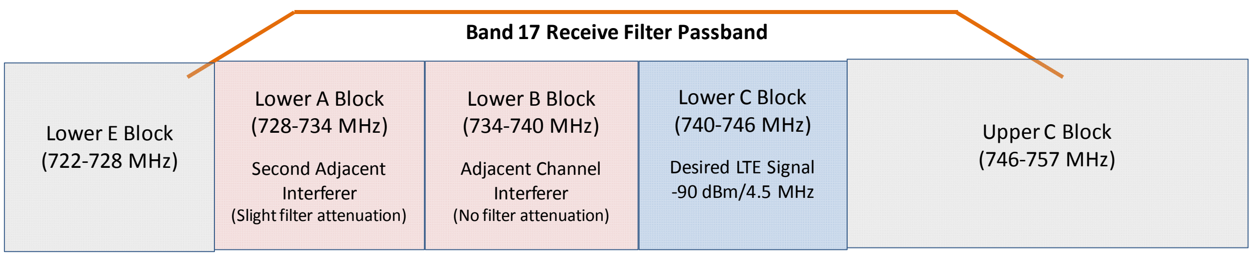


Figure 4.1: Interferer Placement in UE Receiver Blocking Test

Subsequent tests moved the interferer lower in frequency into the Lower A Block to validate the second-adjacent blocking performance. This test configuration would be identical to the case of a Lower E Block interferer adjacent to the passband of a Band 12 device duplexer.

The receiver blocking test measurements are provided in Tables 4.3 and 4.4 for the two types of device under test. In the tables, receiver selectivity is calculated as the delta between the interferer power level and the Lower C downlink LTE signal level. For instance, for the first measurement with the interferer in the adjacent channel, the AT&T USB modem withstood an interfering signal of -29 dBm in the B Block with the desired C Block signal level at -90.3 dBm. The receiver selectivity was calculated as (-29 dBm - -90.3 dBm) = 61.3 dB.

Interferer Location	Interferer Center Frequency (MHz)	Upper Edge of Interfering Frequency (MHz)	Frequency Separation (MHz)	Interferer Power Level/4.5 MHz (dBm)	LTE BLER %	Receiver Selectivity (dB)
Lower B	736.25	738.5	1.75	-29	2%	61.3
Lower B	735.25	737.5	2.75	-23	1%	67.3
Lower A/B	734.25	736.5	3.75	-21	5%	69.3
Lower A/B	733.25	735.5	4.75	-20	1%	70.3
Lower A/B	732.25	734.5	5.75	-18	2%	72.3
Lower A	731.5	733.75	6.5	-17	1%	73.3

Table 4.3: AT&T USB Modem Receiver Blocking Test Results

Interferer Location	Interferer Center Frequency (MHz)	Upper Edge of Interfering Frequency (MHz)	Frequency Separation (MHz)	Interferer Power Level/4.5 MHz (dBm)	LTE BLER %	Receiver Selectivity (dB)
Lower B	736.25	738.5	1.75	-30	1%	60.3
Lower B	735.25	737.5	2.75	-23	1%	67.3
Lower A/B	734.25	736.5	3.75	-22	0%	68.3
Lower A/B	733.25	735.5	4.75	-20	1%	70.3
Lower A/B	732.25	734.5	5.75	-18	1%	72.3
Lower A	731.5	733.75	6.5	-16	1%	74.3

Table 4.4: AT&T MiFi Receiver Blocking Test Results

The test results for the Lower B Block interferer demonstrate the considerable protection provided by the device receiver components. The B Block interferer fell completely within the Band 17 RF filter, which means that the duplexer played no role in mitigating the strong interferer. The device receiver components other than the duplexer handled an interfering signal which was 60 dB stronger than the desired signal. The commercial device thus performed 28 dB better than the 3GPP minimum specifications.

The receiver blocking test results are plotted in Figure 4.2 below.

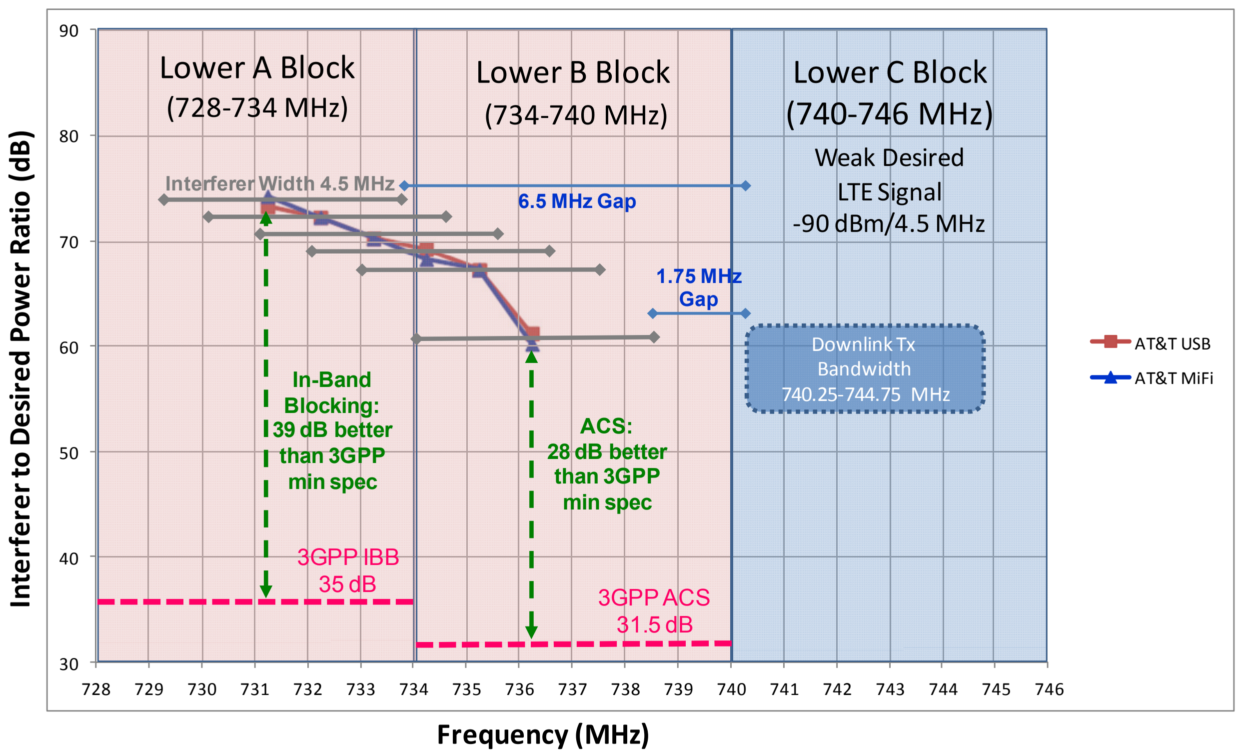


Figure 4.2: AT&T Commercial Device Receiver Blocking Test Results

Tests of the second-adjacent channel (Lower A) demonstrated a tolerance for interfering signals 73 to 74 dB stronger than the desired signal. This IBB performance is 39 dB better than the 3GPP reference receiver specification.

The Lower A Block is adjacent to the Band 17 receive filter passband. The Band 17 tests conducted with a Lower A Block interfering signal would be identical to Band 12 tests with the interferer placed in the Lower E Block. The frequency gap between the desired and interfering signals is the same, and the interferer is similarly placed in the block adjacent to the duplexer passband. Therefore, a Band 12 device operating in the Lower B Block would tolerate a Lower E Block signal up to 73 dB stronger than its desired signal.

The commercial devices perform considerably better than the 3GPP minimum blocking specifications. Additional frequency separation considerably improves the receiver selectivity, as evidenced by the 13 dB improvement from the adjacent channel to the second-adjacent channel.

In other words, the commercial device blocking performance of the Lower B Block to Lower E is at least 13 dB better than the Lower A to E performance. In the laboratory tests, the closest spacing between the desired and interfering signals was 1.75 MHz, driven by the OOBE filter response. In a Lower A Block deployment, the Lower A LTE frequency spacing to E Block would be 1.25 MHz, 500 kHz closer to the interfering signal. This reduced frequency separation may reduce A Block device selectivity to E Block to below the measured 60 dB. Thus, the Lower A Block would be more susceptible to blocking than the Lower B and C Blocks by at least 13 dB, and possibly more. While the reduced A Block selectivity may be cause for concern for A Block licensees, this is not an issue which would impact Lower 700 MHz interoperability. Device performance in the Lower B and C Blocks is considerably better than the Lower A Block performance. Lower 700 MHz interoperability may be granted without interference to Lower B and C Block device reception. Any E Block power modifications to manage A Block interference would be a separate issue unrelated to interoperability.

The next step in the analysis is to measure the signal levels for the Lower E Block broadcast sites and LTE towers in a field environment. The field measurements will determine whether the E Block RF environment may cause interference to commercial devices operating in the Lower B and C Blocks.

4.3 E Block and LTE Systems Present Similar Ground-Level Signals

AT&T's 2008 3GPP contribution contained a theoretical analysis suggesting that the Lower E Block ground-level power could reach -25 to -30 dBm[13]. However, AT&T did not consider that an LTE base station would regularly produce similar ground-level signals.

A theoretical comparison of Lower E Block and LTE downlink power is provided in Table 4.5.

	Lower E Broadcast	LTE Base Station	
Downlink ERP	77	58	dBm
Downlink EIRP	79	60	dBm
Antenna height (AGL)	150	30	m
Distance from tower to device	250	250	m
Angle to device	31	7	degrees
Antenna downtilt	0	3	degrees
Antenna gain reduction toward device	-10	0	dB
Angular distance to device	292	252	m
Free Space Path Loss	79	78	dB
Body/coupling losses	10	10	dB
UE antenna gain	-5	-5	dBi
Signal level at device	-25	-33	dBm

Table 4.5: Lower E and LTE Ground-level Power Calculations

The broadcast Lower E Block system attempts to maximize coverage range, employing tall towers and focusing antenna energy toward the horizon. The LTE system attempts to maximize system capacity, employing antennas at lower mounting heights and using antenna downtilt to confine the RF energy within the sector's coverage area. The different approaches to site design affect the ground-level signals near the transmission towers. Even though the broadcast tower has a radiated power level 19 dB higher than the typical LTE site, the differences in antenna height and directionality reduce this difference to 8 dB at ground level.

Recall that the commercial devices demonstrated a 13 dB improvement in selectivity between the adjacent channel and the second-adjacent channel. Thus, the Lower E Block broadcast, with a maximum of 8 dB stronger ground-level signal than an LTE system, would present a 5 dB lower signal level to a Band 12 device operating in the Lower B and C Blocks than would an LTE base station operating in the adjacent channel, as in the case of a VZW base station transmission. The Lower E Block therefore presents a more readily managed signal level to Lower B and C devices than the many thousands of VZW base stations.

On the other hand, the Lower A Block is immediately adjacent to the Lower E Block, and has at least 13 dB less selectivity than the same device operating in the Lower B and C Blocks. The Band 12

[13] 3GPP TSG RAN WG4 #47bis, Munich, Germany, AT&T, R4-081324 "Performance and coexistence issues in the Lower 700 MHz band", June 2008, p. 3.

device operating in the Lower A Block may therefore be exposed to up to 8 dB stronger Lower E Block signal levels than the signals from nearby LTE base stations. This situation is a Lower A Block deployment issue unrelated to Lower 700 MHz interoperability. While a reduction in Lower E Block ERP may facilitate Lower A deployment, such a condition on the E Block is not a prerequisite for Lower 700 MHz interoperability because the Lower B and C Blocks are unaffected.

The Atlanta field measurements confirm the theoretical calculations regarding the Lower E Block power level relative to LTE base station signals.

From section 4.1, we determined that a 3GPP reference receiver could begin blocking if it were receiving a weak AT&T signal near a VZW downlink signal stronger than -56 dBm. The converse is also true; a 3GPP reference receiver using the VZW system could be affected if the neighboring AT&T downlink signal is greater than -56 dBm. Figure 4.3 is a coverage plot of the measured signal levels in Atlanta for the AT&T system.

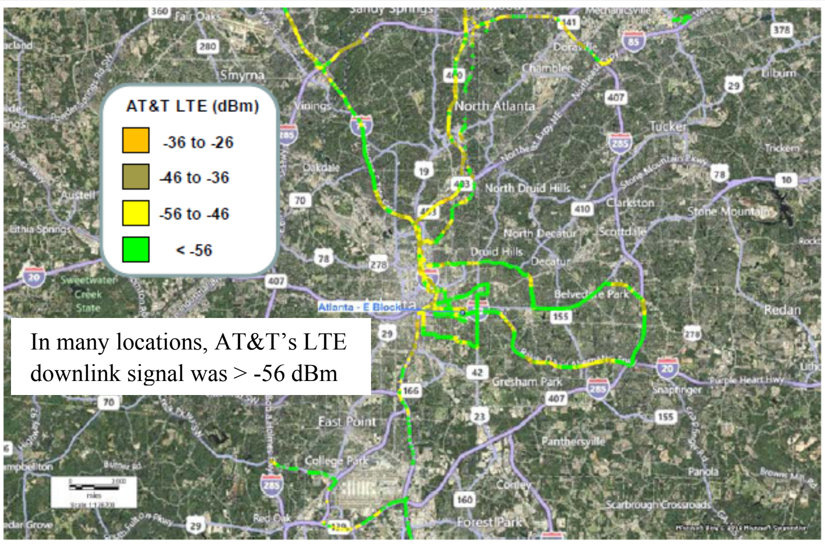


Figure 4.3 Signal Strength: AT&T LTE System in Atlanta

Throughout much of Atlanta, AT&T's downlink signal strength was greater than -56 dBm (yellow, brown, and orange data points). A 3GPP reference receiver serving on the neighboring Verizon Wireless system could experience receiver blocking in these areas, if the VZW downlink signal strength was low.

Figure 4.4 provides the VZW downlink signal strength in Atlanta.

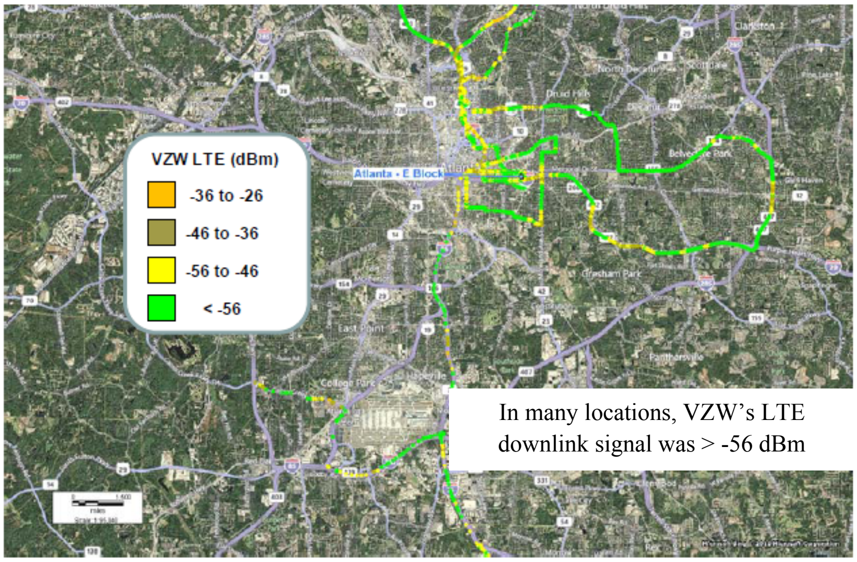


Figure 4.4 Signal Strength: VZW LTE System in Atlanta

As with AT&T, throughout much of Atlanta, VZW's downlink LTE signal strength was greater than -56 dBm. A 3GPP reference receiver could similarly be affected throughout much of the VZW service area.

The ground-level signals for the Lower E Block broadcast system are often greater than -56 dBm, as shown in Figure 4.5.

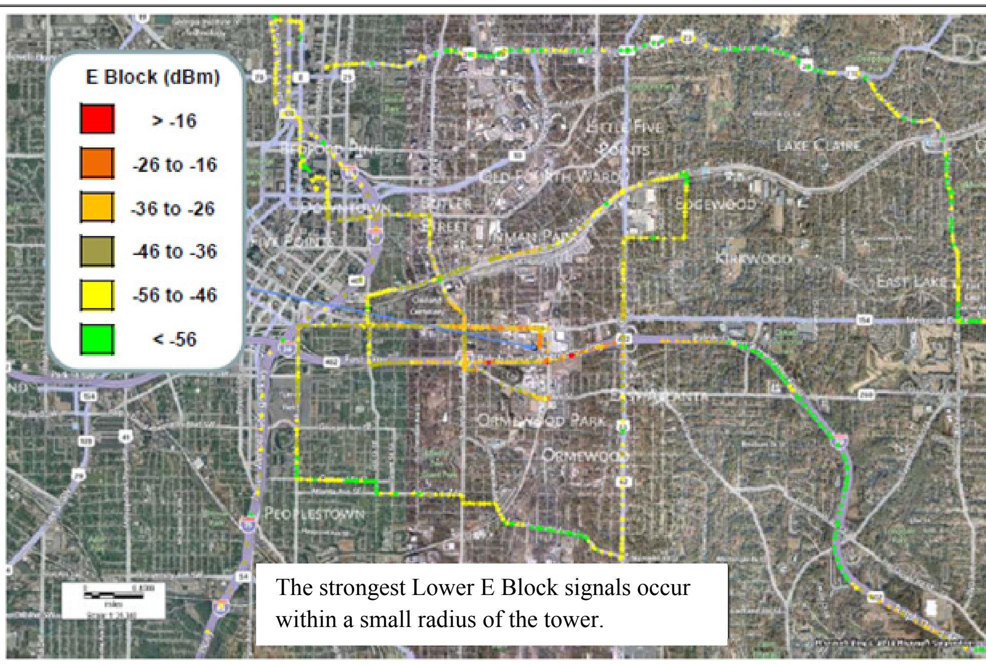


Figure 4.5 Signal Strength: Lower E System in Atlanta

The field measurements of commercial LTE systems illustrate the variability of signals within compatible operating systems. Extremes of signal strength may exist near any LTE base station.

Annex A.1 provides further evidence that systems similar to LTE produce strong ground-level signals. Motorola performed measurements of cellular systems and noted several locations where ground-level signals were stronger than -20 dBm.

Annex A.2 provides measurements of path loss for an 850 MHz system. The signal levels shown are adjusted to represent LTE downlink signal strength. The test showed a ground-level signal as strong as -28 dBm at a distance of 600 meters from the base station.

Clearly, downlink signals from neighboring LTE systems may present ground-level signals which are nearly as strong as Lower E Block signals. Devices designed to handle strong adjacent LTE signals would similarly handle strong Lower E Block signals.

4.4 Commercial UE Design is Driven by Coexistence with Neighboring LTE Systems

As noted in section 4.3 and Annex A, the LTE downlink signal level in the vicinity of a base station may exceed -30 dBm. Furthermore, the coverage of a neighboring LTE system will often exceed the 3GPP blocking specification of -56 dBm. A 3GPP reference receiver could experience blocking when near a neighboring system's LTE base stations. Commercial devices, therefore, must be designed to perform better than the 3GPP reference receiver in order to maintain acceptable performance when near neighboring LTE base stations.

An example of how a neighboring LTE system may present a power ratio exceeding the 3GPP minimum specifications is provided in Figure 4.6.

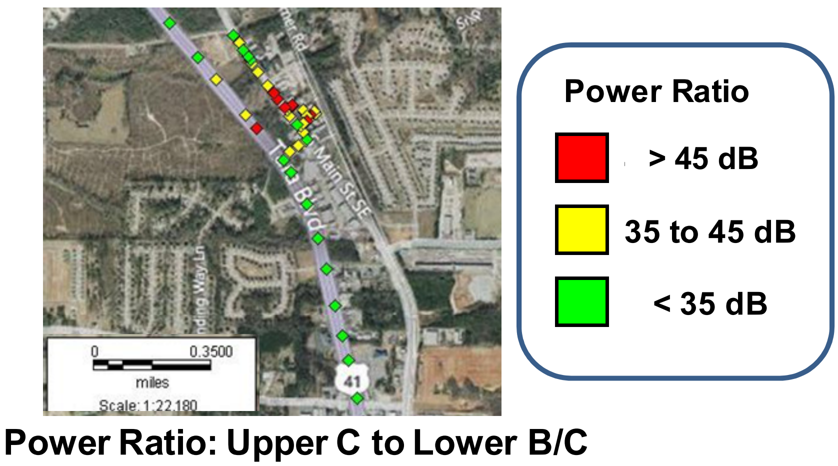


Figure 4.6: Power Ratio of VZW to AT&T LTE Coverage

Figure 4.6 provides a comparison of the power of AT&T's LTE downlink in the vicinity of a Verizon Wireless LTE site. The Upper C Block LTE signal is much stronger than the AT&T signal. The highest power differential measured at this site is 48 dB; the VZW signal level was -34 dBm and the AT&T signal was -82 dBm. Since stronger LTE downlink signals may be encountered, some additional design margin beyond 48 dB would be desirable in the commercial device design.

To handle this normal operational scenario of neighboring LTE systems, the commercial device must be designed to handle an adjacent channel signal which is 55 to 60 dB stronger than the desired signal. Such a design criteria is (60 – 31.5) = 28.5 dB more stringent than the 3GPP adjacent channel selectivity requirement of 31.5 dB.

As verified in the laboratory test results in section 4.2, the commercial devices provided an adjacent channel selectivity of 60 dB, which provides a sufficient margin to protect devices from the difference in power levels which may be experienced between neighboring LTE systems. Thus, the receiver design of commercial devices is driven by the need to protect UE performance in the presence of adjacent LTE systems.

Practically speaking, then, Band 17's tighter 3GPP blocking specification for the Lower E Block does not drive the commercial device design. An AT&T Band 17 device must be designed to perform normally throughout the market – even in situations where the device is closely approaching a Verizon Wireless LTE base station in the Upper C Block. The VZW downlink transmission is immediately adjacent to the Band 17 receiver filter passband, and will not be reduced by RF filter attenuation. The device receiver components must be designed to handle strong signal differentials in such conditions, without reliance on the RF filter.

Site coordination is not a feasible approach to manage LTE-base-to-LTE-device interference throughout a system. The 700 MHz LTE operators will deploy tens of thousands of base stations nationwide. Attempting to coordinate site locations with multiple operators across thousands of locations is an impossible task. Instead, the device vendors design commercial devices to handle the extremes of signal levels commonly found in operating systems. This superior commercial device design, necessary to handle neighboring LTE base station signals, also adequately protects devices operating in the Lower B and C Blocks from the Lower E Block broadcast transmissions.

The next section examines the Lower E Block power relative to the two commercial LTE systems in Atlanta.

4.5 E Block Power Ratios Show No Interference to Commercial LTE Devices

The laboratory testing established that commercial Band 12 devices operating in the Lower B and C Blocks would perform normally in the presence of Lower E Block signals up to 73 dB stronger. The commercial device performance may be compared against the RF environment in Atlanta to determine whether interference may exist when near Lower E Block broadcast towers.

The field measurements in Atlanta collected signal levels for the AT&T and VZW LTE systems and the Lower E Block broadcast system. Figure 4.7 provides a plot of the ratio of Lower E Block power to AT&T LTE downlink power surrounding the Dish "Atlanta" broadcast site.

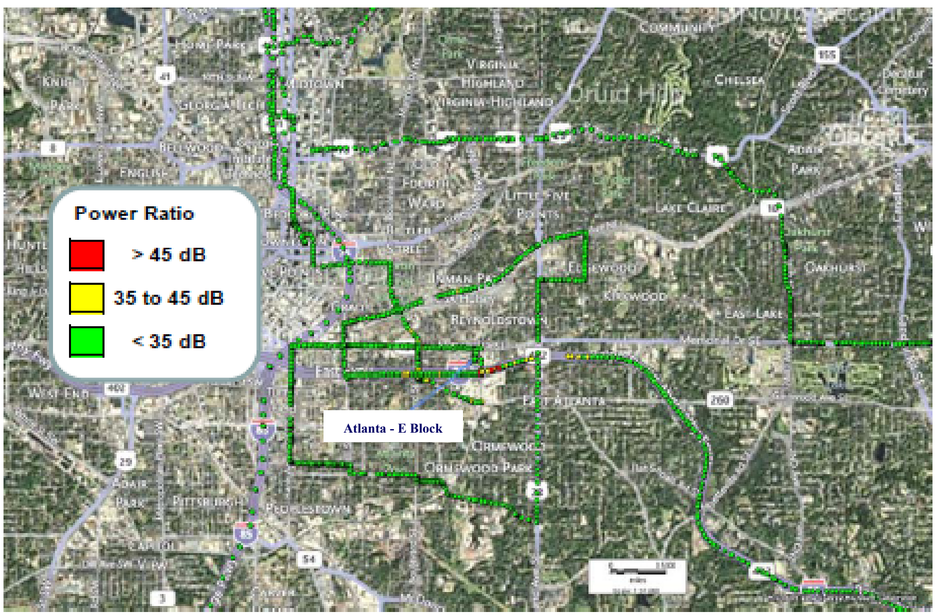


Figure 4.7 Power Ratio: E Block versus AT&T (Atlanta Site)

Nearly all of the data points around the Atlanta site remain within the 3GPP reference receiver specification of 35 dB. None of the measurements exceeded the commercial device blocking performance of 73 dB. No interference would result to Lower B and C Block device reception. A closer view near the Atlanta tower is provided in Figure 4.8.

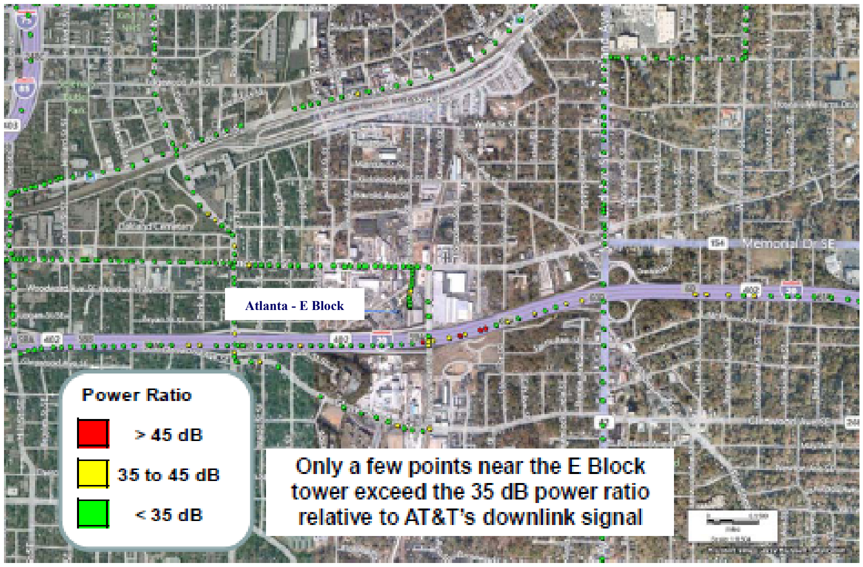


Figure 4.8 Power Ratio: E Block versus AT&T (Atlanta zoom)

Similar plots of E Block signal strength relative to the Verizon Wireless system are provided in Figures 4.9 and 4.10.

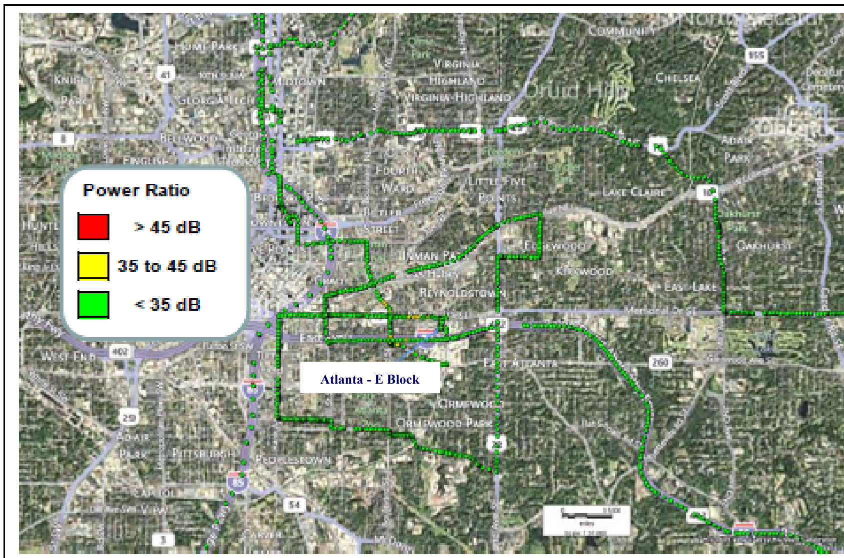


Figure 4.9 Power Ratio: E Block versus VZW (Atlanta site)

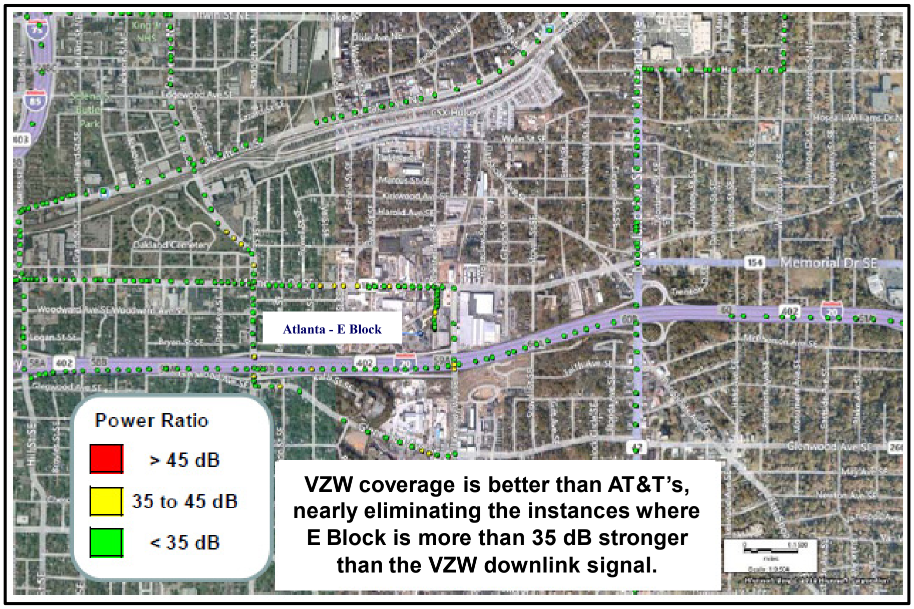


Figure 4.10: Power Ratio: E Block versus VZW (Atlanta site)

As evident from the figures, the Atlanta E Block site is located in a light urban/suburban environment where LTE systems should provide consistent coverage throughout the area tested. The power ratio of the E Block to the LTE signals remained well below the levels tolerated by the commercial devices. No interference would exist to Lower B and C Block operation.

Measurements near a second E Block broadcast tower are provided in Figure 4.11. The Dish tower in Fayetteville is located southwest of Atlanta in a light suburban to rural environment. Figure 4.11 provides the power ratio of the E Block signal relative to AT&T LTE coverage near the tower.

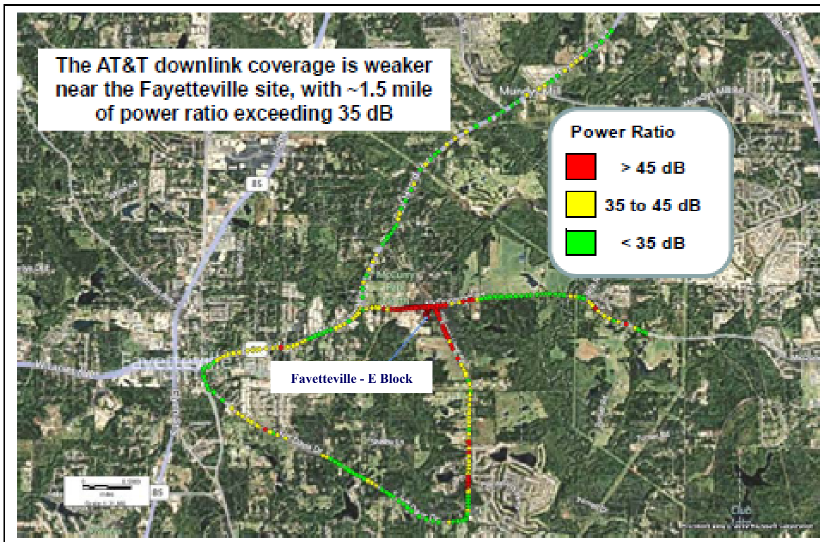


Figure 4.11 Power Ratio: E Block versus AT&T (Fayetteville Site)

An analysis of the AT&T signal levels near the Fayetteville site show that this area is on the fringe of AT&T's LTE coverage. The VZW signal levels in the same area are consistently stronger than AT&T's. Figure 4.12 provides the coverage comparison of AT&T and VZW as a function of distance from the Fayetteville site.

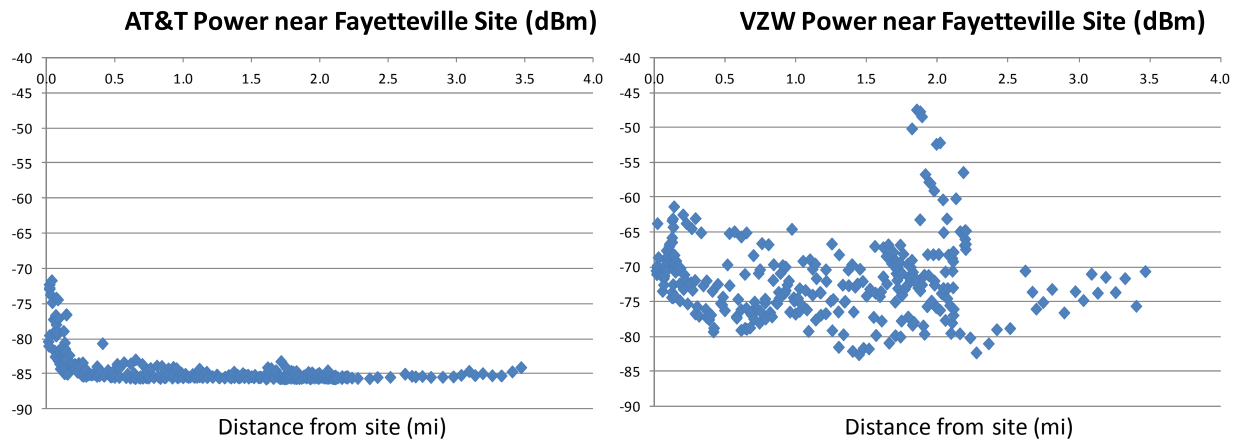


Figure 4.12: AT&T and VZW LTE Coverage Near Fayetteville Broadcast Site

The AT&T LTE coverage around the Fayetteville site was weak in comparison to the VZW coverage. Therefore, the Fayetteville site provides the ideal testing ground to evaluate receiver blocking: weak desired AT&T coverage is in the same geographic area as a strong Lower E Block broadcast site.

Even in this worst case situation where the closest AT&T LTE site is far away from the Lower E Block tower, a commercial device would not experience interference. Plotting the power ratios of E Block to the AT&T and VZW LTE coverage shows that, even directly under the Dish tower, the power ratio is well below the limit tolerated by commercial devices operating in the Lower B and C Blocks. Figure 4.13 provides this view.

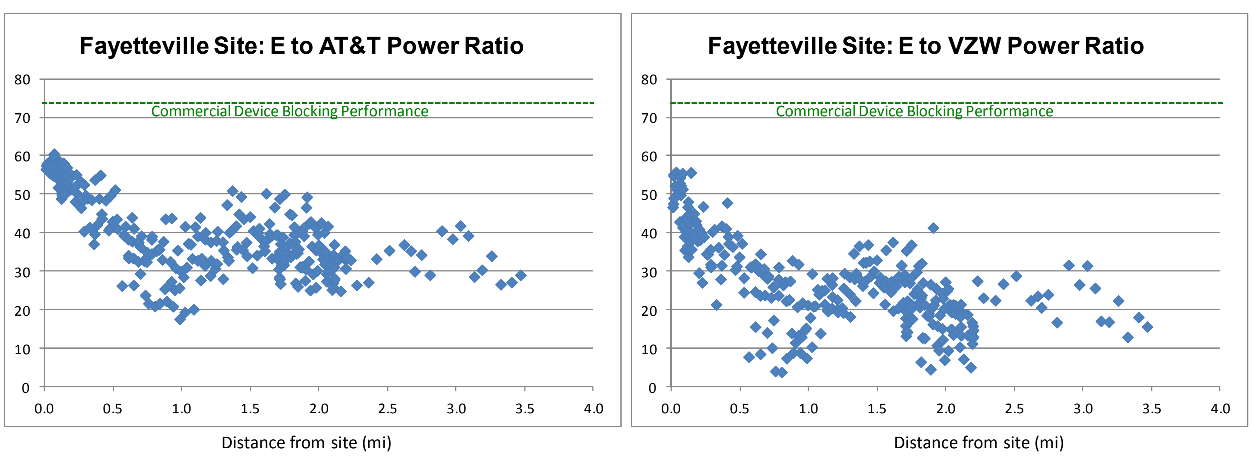


Figure 4.13: Dish Broadcast Power Ratio Relative to AT&T and VZW LTE

Comparing Figure 4.12 to 4.13 reveals that the VZW system, with stronger coverage in the test area, achieves a lower E Block power ratio relative to AT&T.

From the laboratory and field measurements, commercial Band 12 devices operating in the Lower B and C Blocks would have a margin of 15 to 30 dB above the worst conditions measured in Atlanta. Such commercial devices would never experience receiver blocking near Lower E Block towers, regardless of the LTE site placement.

The Lower A Block, directly adjacent to the Lower E Block, may be more susceptible to blocking interference. From the lab tests, the commercial devices tolerated an adjacent channel signal 60 dB stronger than the desired signal. This leaves little margin for Lower A Block operation, as shown in Figure 4.14. Figure 4.14 illustrates the different blocking performance of the commercial devices for the Lower A, B and C Blocks.

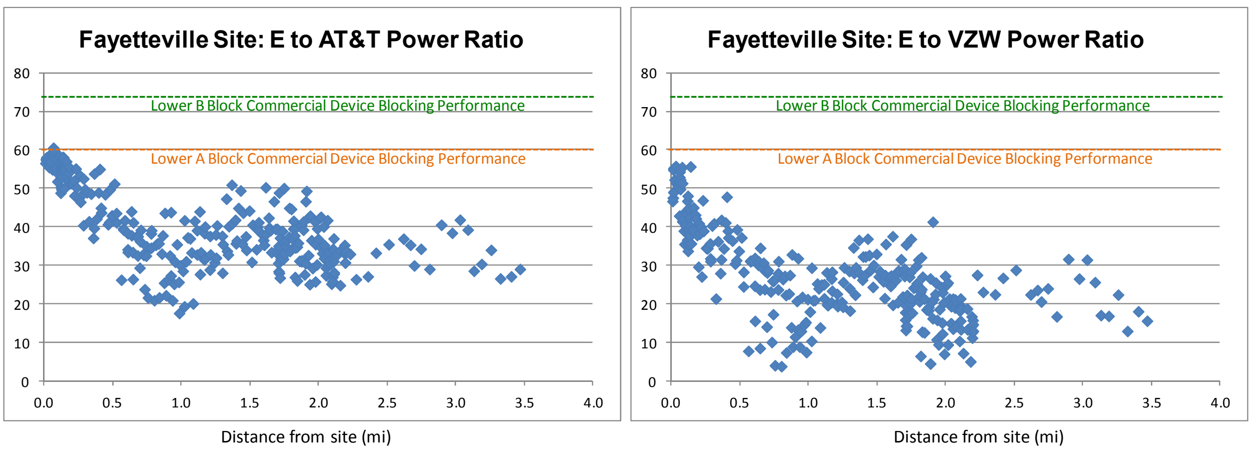


Figure 4.14: Lower A and B Block Commercial Device Performance

While the Lower B and C Blocks have an excess margin of at least 13 dB, the Lower A Block, with its reduced frequency separation, has no excess margin when near an E Block tower. Thus, Lower A Block device reception may benefit from a reduction of the regulatory ERP limit within Lower E Block to provide a margin for commercial devices. This condition on the E Block is not a prerequisite to Lower 700 MHz interoperability since Lower B and C Block device performance already provides a considerable margin.

In summary, the highest power ratio measured in Atlanta of the Lower E Block to an LTE system was 60 dB, directly underneath the Dish tower. The AT&T commercial devices are capable of tolerating a second-adjacent signal which is 73 dB stronger than the desired signal. The Band Class 17 RF filter is not needed to prevent interference – the device receiver components are designed to handle the spread of RF signal levels which may result near Lower E Block broadcast towers. This device behavior is essential to protect device reception from strong signals in adjacent LTE systems, such as the Upper C Block and Lower A Block.

Band Class 12 devices receiving in the Lower B and C Blocks would not experience interference in the vicinity of Lower E Block towers – Band Class 17 is not needed. The Lower E Block does not present a credible interference threat to Lower B and C device reception.

4.6 Band 12 Systems Meet 3GPP Reference Receiver Specifications

The 3GPP reference receiver is a hypothetical device. Device manufacturers exceed the minimum 3GPP specifications to ensure their final product passes compliance testing and to avoid interference from adjacent LTE systems. Nevertheless, for avoidance of doubt, we will demonstrate how a Band 12 Lower B and C Block system in a Lower E Block market may support these hypothetical devices performing at the minimum 3GPP specifications.

The 3GPP reference receiver in-band blocking specifications tolerate a Lower E Block signal 35 dB stronger than a Lower B Block signal and 47 dB stronger than a Lower C Block signal. The Band 12 base stations may be selected such that the LTE signal near the Lower E Block broadcast station is strong. The VZW system design around the Dish Atlanta Site provides an excellent example of how the base station placement within the system can meet the 3GPP minimum specifications. A handful of data points within a few blocks of the tower exceed the 35 dB power ratio but remain below 45 dB. Thus, Lower C Block performance would be unaffected – all power ratios remain below the 47 dB minimum specification. Lower B Block, with a minimum specification of 35 dB, may have a few meters of coverage area where the device will be assigned C Block downlink resource blocks if the Lower B resource block quality is slightly impacted for these hypothetical receivers.

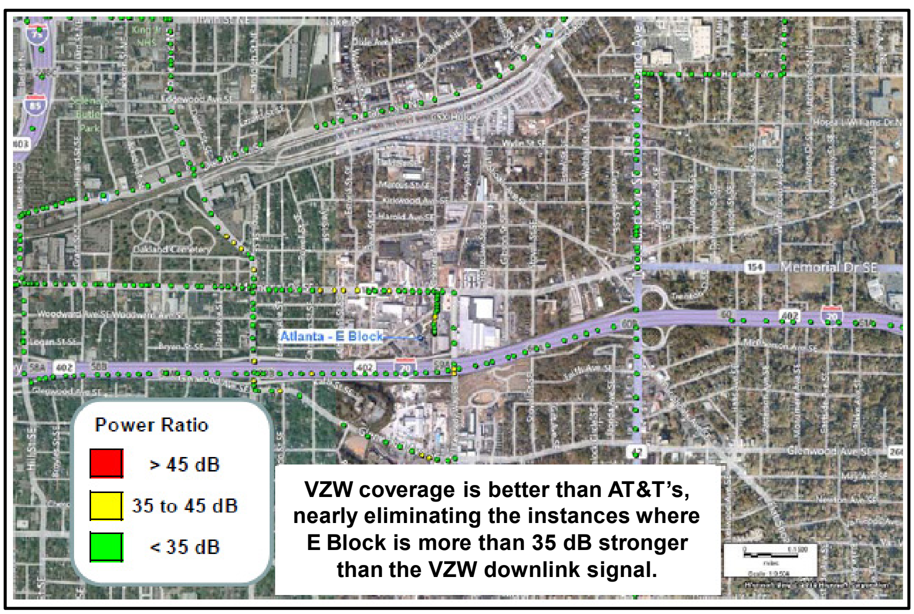


Figure 4.15: E Block to VZW LTE Power Ratio near Atlanta Site

The VZW system was not purposefully designed to deliver strong LTE coverage near the E Block tower. By planning the initial system design to place one Band 12 site closer to the E Block tower, the data points with a power ratio higher than 35 dB would be eliminated.

Moreover, LTE systems are designed to meet a minimum threshold of coverage which is defined by a target power level that the operator aims to exceed at ground level throughout the market. In urban areas, operators design for in-building coverage, planning significant margins in order to ensure signal penetration of tall buildings with dense construction materials. In suburban and rural areas, the design threshold may be lower because the signal penetration loss for homes and vehicles is lower. In all areas, the ground-level signal must be considerably stronger than the minimum receive sensitivity of the device to ensure that the device will work inside cars and buildings.

For the Verizon Wireless LTE system within ten miles of the Atlanta Lower E Block site, the design threshold appears to be -80 dBm based on the VZW signal strength plot in Figure 4.16.

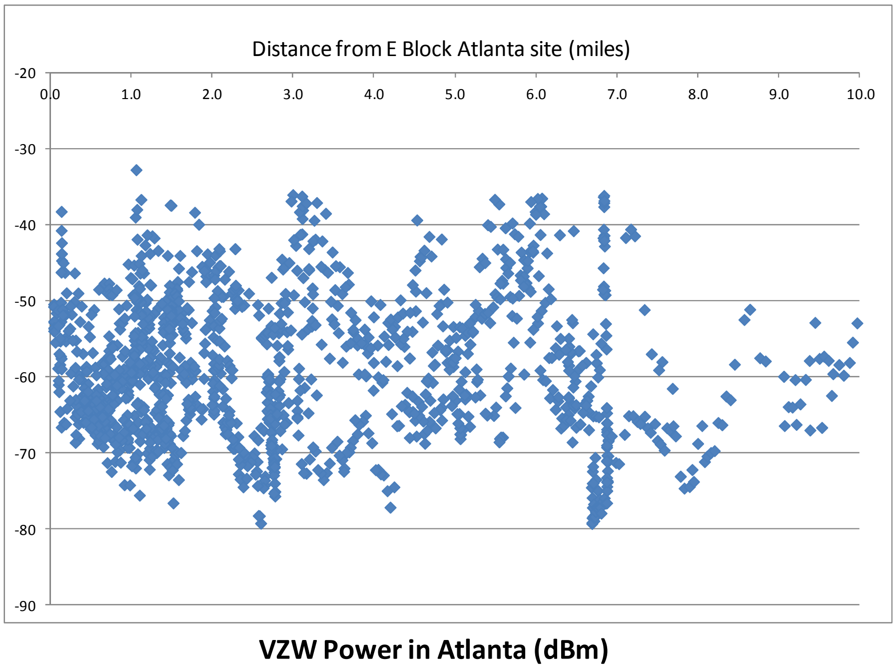


Figure 4.16: Verizon Wireless LTE Coverage

The lowest VZW signal collected on the roads within ten miles of the Atlanta site was -80 dBm. As one LTE site's coverage begins to fade, the next site down the road increases in strength, such that the LTE device consistently receives desired signals of -80 dBm or higher. This concept of designing the LTE system to meet a target coverage level increases the built-in protection to the hypothetical 3GPP reference receiver. For instance, an LTE reference receiver in a coverage area near the LTE cell edge will perform normally in the presence of a Lower E Block signal of (-80 + 35 dB) = -45 dBm. In areas where the E Block signal is greater than -45 dBm (near the E Block tower), then the LTE system may be designed to provide a stronger signal level than the target minimum, readily achieved by ensuring the few Lower E Block towers in a market do not fall on the cell edge boundaries of the LTE system.

Figure 4.17 illustrates the Lower E Block measurements within a few miles of the Fayetteville tower. The orange line provides the theoretical signal level predicted by the Hata propagation model, with 10 dB of clutter loss incorporated. Near the tower, the propagation model predicts stronger signals than those measured – as expected given the antenna focus toward the horizon. Less antenna gain is available toward the ground near the broadcast tower.

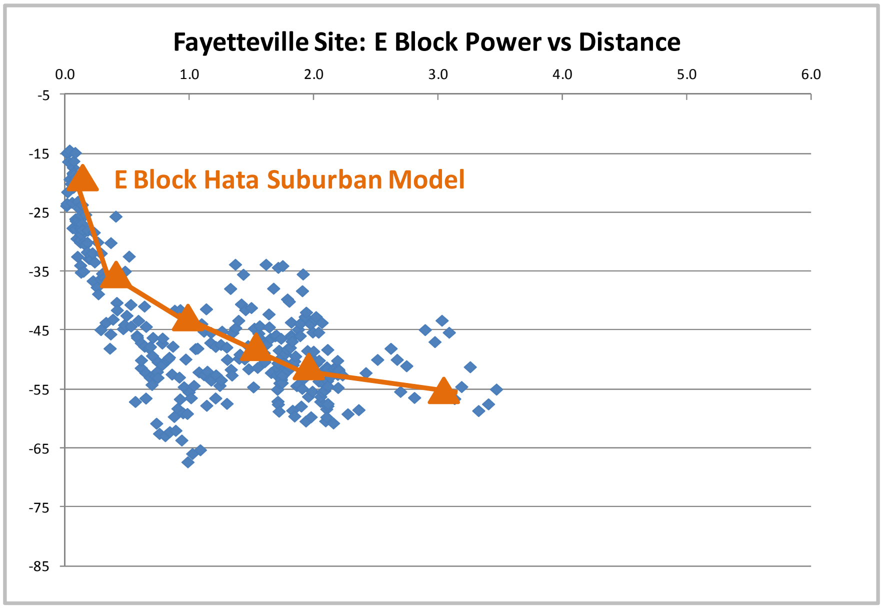


Figure 4.17: E Block Measured and Predicted Coverage for Fayetteville Site

The Fayetteville antenna is mounted 150 meters above the ground in a light suburban to rural area, as shown in Figure 4.18.

Figure 4.18: Satellite View of Fayetteville Site and Vicinity

If the E Block system was deployed first and the LTE system was designed later, then the LTE site selection process could place a base station in the vicinity of the E Block tower and completely eliminate any blocking interference to the hypothetical 3GPP reference receiver. The LTE site installed close to the E Block tower would provide a strong signal where the E Block signal is strong. At the edge of coverage for the LTE system, neighboring sites provide increasingly stronger signals and manage the E Block coverage differential. This relationship is essentially what was observed for the Verizon Wireless system near the Atlanta site, earlier in the report.

The LTE signal strength as it relates to the E Block signal strength is modeled in Figure 4.19. The signal strength in dBm is plotted as a function of the distance in miles from the Lower E Block site.

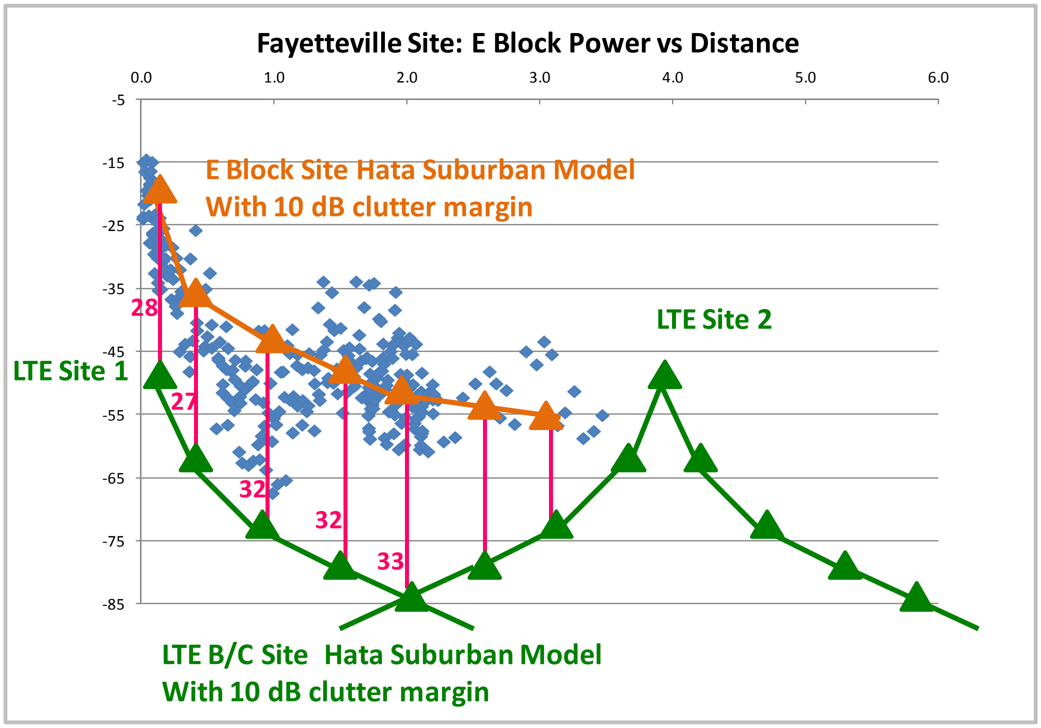


Figure 4.19: LTE Coverage Comparison with E Block

In Figure 4.19, the first LTE site is located near the Lower E Block tower, at the left side of the figure. The LTE signal strength is predicted with the same Hata propagation model with 10 dB of clutter loss, but using an LTE antenna mounting height of 30 meters. This lower mounting height combined with the reduced transmission power of the LTE site greatly reduces the coverage range relative to the Lower E Block broadcast. Given the relatively rural nature of this site, the operator may choose to increase the LTE antenna height above 30 m to extend the coverage range. Such an increase in coverage would further improve the LTE signal with respect to the E Block signal.

The LTE signal strength declines as the distance from the site increases. As the coverage from LTE Site 1 reaches the design threshold, assumed to be -85 dBm in this rural area, the next LTE site in the system becomes the dominant server, with increasingly stronger signal levels as the distance from the E Block site continues to increase. The second LTE site is assumed to be deployed at a distance of four miles from the E Block tower in Figure 4.19, resulting in a 2 mile coverage radius per LTE site.

The pink numbers in the figure provide the power ratio between the Lower E Block and LTE signal from the Hata propagation model. At all points, the ratio remains below 35 dB, the minimum specification for Lower B Block blocking performance.

The blue dots represent field measurements which fall above and below the signal level predicted by the Hata model. The coverage around the site varies depending on the radial direction from the site.

As seen from Figure 4.18, some measurement areas have a clear line-of-sight to the tower, and others are obscured by trees. Slight terrain differences also introduce a variance in the measured signal as a function of distance from the tower. These differences would be identical for an LTE site deployed in the same area as the E tower; the measured signals from the two systems would experience similar crests and fades, and remain within the 3GPP blocking specification. If a further abundance of caution is desired, other measures such as a taller LTE radiation center or increased downlink power at this one site would provide more than sufficient margin to prevent interference to Lower B and C Block device reception for the hypothetical reference receiver.

With such a system design approach, the hypothetical 3GPP reference receiver would never experience blocking in the Lower B and C Blocks.

Note that the Lower A Block reference receiver would only tolerate a Lower E Block signal 31.5 dB stronger than the desired signal. The theoretical study presented above provided adequate protection to the Lower B Block, but fell slightly short of the Lower A Block level. Power reductions at Lower E Block broadcast sites could facilitate A Block deployment, but such reductions are not a prerequisite to Lower 700 MHz interoperability.

If the LTE system is deployed first and a Lower E Block broadcast system is deployed at a later time, then the incumbent LTE operator has the right to be protected from harmful interference caused by the Lower E Block transmissions. The Lower E Block operator must design its broadcast system in such a manner that interference does not result to Band 12 devices. The Lower E Block operator may manage ground-level energy through antenna pattern modifications or reduced transmission power, or may seek to deploy broadcast towers at locations where Band 12 system coverage is strong. In any case, the E Block operator must correct any interference that might be caused to incumbent Band 12 operations.

In conclusion, a Band 12 Lower B and C Block operator may plan their system design to prevent interference to the hypothetical 3GPP reference receivers. Such planning would not incur added cost, but would simply add one further consideration in the site selection process. No additional sites or other equipment would be needed to ensure adequate reception for Lower B and C devices.

As a final reminder, commercial devices perform considerably better than the 3GPP minimum specifications. The question of how best to support hypothetical 3GPP reference receivers in a Band 12 system is a purely theoretical exercise, but one which could be easily implemented should the need ever arise.

4.7 Atlanta E Block Measurements are Valid

AT&T has claimed[14] that the Atlanta E Block measurements do not represent a realistic case of commercial mobile video interference because Dish only deployed four broadcast sites to cover Atlanta, versus the thirteen sites previously employed by Qualcomm. AT&T's statement is incorrect. When evaluating receiver blocking, the number of towers in the city is immaterial. Only the strong signals in the near vicinity of a tower are of sufficient power to potentially cause blocking. Proving the sufficiency of the Atlanta measurements is a simple exercise in mathematics.

A mobile video broadcast system is designed to cover a wide area with as few sites as possible. If the broadcast system is designed to provide a signal strength of at least -80 dBm at the midpoint between two broadcast towers, then the signal level from Tower One would be considerably weaker than -80 dBm in the vicinity of Tower Two.

The mobile video broadcast system deployed by Dish employs omnidirectional transmissions from each site. At the worst case midpoint among neighboring sites, there would be at most three sites with additive interference. The other broadcast towers would be too far away to contribute any meaningful power.

To mathematically demonstrate the fallacy in AT&T's claim, we will consider the unrealistically pessimistic case of twelve interferers arriving simultaneously at equal power. If we assume that the twelve interferers each arrive with signal levels of -80 dBm and add to a Lower E Block serving signal level of -56 dBm, the resulting power level becomes:

Power Level = -56 dBm + (Twelve signals at -80 dBm) = -55.8 dBm

Thus, in this unrealistic case of twelve equal-power interferers combining, the possible impact to a -56 dBm E Block signal is an increase of 0.2 dB. The increase in E Block signal strength at points closer to an E Block tower would be even lower, because the measured E Block signal would be even stronger than -56 dBm and the contributing interfering signals would be weaker. Such a miniscule signal difference of a few tenths of a dB is not discernible in field testing. The Atlanta measurements provide a valid representation of the signal levels from a Lower E Block broadcast video deployment.

[14] AT&T ex parte in WT Docket No. 11-18, RM 11592, December 7, 2011, p. 2: "To assess the potential for E Block to Band 12 device interference, Vulcan tested the signal level of a network deployed with four transmitters in Atlanta, GA. In a March 6, 2011, Notice of Ex Parte Presentation, Qualcomm advised the Commission that it required 13, not four, transmitters to adequately serve the Atlanta market, which would lead to higher E Block signal levels. Further, it is unclear whether the E Block transmitters for which Vulcan measured the signal level were operating at maximum power. Thus, Vulcan's assumptions underlying its E Block testing also do not reflect what may be experienced in the real world."

5. Channel 51

Following Auction 73, the FCC permitted Channel 51 (692-698 MHz) to remain allocated for digital television (DTV) transmissions. Full service DTV stations may transmit with up to 1 MW of power. Channel 51 may also be employed for low-power television (LPTV) service on a secondary basis, with an ERP of up to 15 kW.

When 3GPP defined band classes for the US 700 MHz Band, the equipment manufacturers recognized the potential for interference from the high-power transmissions and assigned the spectrum blocks closest to 698 MHz as base station uplink, or receive. The device receive blocks (728-746 MHz) would have 30 MHz of separation from the DTV transmissions, more than sufficient frequency separation to avoid any blocking or OOBE concerns. From this perspective, DTV 51 did not pose an interference threat to Band Class 12 device reception.

By placing base station reception adjacent to DTV 51, 3GPP provided operators with flexibility in controlling base station interference from the high-power broadcasts. For instance, an operator deploying LTE in the Lower B and C Blocks could employ a base station receive filter which only passes 704-716 MHz. This base station filter would provide considerable rejection of the DTV 51 signal. Operators commonly employ base station filters with a narrower passband than the Band Class frequency range in order to improve rejection of nearby signals. This practice does not impact the band class specification. In other words, a Band Class 12 base station may employ a receiver filter only covering 704-716 MHz and still be compliant with the Band 12 specifications.

The emissions from DTV 51 stations are filtered considerably as required by the FCC rules. Therefore, OOBE is not an interference concern to Lower B and C base station operation.

While OOBE and base station receiver blocking remain valid concerns for Lower A Block base stations, no impediments are raised to Lower B and C Block base station performance. Band Class 12 could be employed with no impact to Lower B and C performance. In the 3GPP deliberations, the base station vendors agreed that DTV 51 concerns as related to Lower B and C base station reception could be handled within the existing Band Class 12[15].

Band 17 proponents raised a device interference concern related to Channel 51 as a reason for introducing the new band class: reverse power amplifier (PA) intermodulation (IM). Reverse PA IM requires three coinciding criteria to cause interference. First, the Channel 51 signal level at the LTE device must be strong. Second, the LTE device must be transmitting at very high power near the upper edge of the 10 MHz LTE channel (Lower C Block). Third, the device must be simultaneously receiving

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[15] Report of the 3GPP TSG RAN WG4 meeting # 47bis, Munich, Germany , 16-20 June 2008. Discussion of R4-081324 “Performance and coexistence issues in the Lower 700 MHz band”, AT&T, p. 28: “Nortel: for the eNodeB filtering can be improved. Qualcomm: analyze the interference situation and they come to conclusions similar to AT&T for the UE, they understand that for the BS the problem can be solved without introducing the 15 band.” Nortel and Qualcomm agreed that Band 15 (17) was not needed to manage base station interference.

on the resource blocks impacted by the intermodulation products (lower end of the Lower B Block). The theory of reverse PA IM is fully explained in section 5.1.

The laboratory test results of reverse PA IM validated that commercial LTE devices are capable of normal operation in the presence of very strong nearby signals, such as the scenario which may result when Channel 51 is employed in a city. The device power amplifier's third order intercept performance is sufficient to reduce the magnitude of any intermodulation products to below the noise floor, even in the worst case condition of the device transmitting at maximum power when in close proximity to a DTV 51 tower. The field measurements validated the RF environment within the city, demonstrating that a DTV tower would not cause interference to Lower 700 MHz device reception. The AT&T devices could employ a Band 12 duplexer without risk of interference from Channel 51 operations.

Moreover, the lab tests validated the substantially limited circumstances under which IM interference could be generated, even if the DTV signal could reach unrealistically high levels. Tests of different UE resource block transmissions demonstrated that block error rates only occurred for UE transmissions in the uppermost 900 kHz of the LTE channel (Lower C Block). Transmissions in the remaining 8.1 MHz of the channel did not cause interference, even with the Channel 51 interfering signal set to the maximum power level produced by the signal generator.

Finally, if the Lower B and C Block operator elects to deploy devices which perform considerably worse than the AT&T commercial devices, a number of management mechanisms are available to completely eliminate any interference concerns.

5.1 Theory of Reverse Power Amplifier Intermodulation

In Motorola's May 2008 contribution to 3GPP, Motorola described a concern from reverse PA IM[16]:

> "(b) For a UE operating in a Band 12 configuration (A+ B+ C), this would result in a significant in-band power when roaming near a channel 51 broadcast transmitter since limited RF filtering would be available for the adjacent Channel 51 if A block is part of the operating bandwidth. This large in band power would intermod with an existing UE transmission in block A, B and C to generate spurious emission ($2F_1$-F_2) in other parts of the 700 MHz spectrum. The key issue for Tx IM is the level of the DTV Channel 51 wideband signal that would be present at the UE antenna port based on a reasonable deployment scenario"

The scenario of concern to Motorola was a situation where a Band 12 device was transmitting at high power near a Channel 51 broadcast tower. The reverse PA IM interference mechanism involves a strong Channel 51 transmission entering the device antenna, passing through the device duplexer with some attenuation[17], and mixing with a strong UE transmission in the device power amplifier. The resulting intermodulation products could re-radiate out through the device duplexer, undergo attenuation by the transmit filter, and then cross over to the receiver, potentially causing interference if the receiver is tuned to the channel affected by the intermodulation product. Figure 5.1 illustrates the interaction of Channel 51 with Lower 700 MHz device transmissions to theoretically produce reverse PA intermodulation. In this case, the UE transmission in Lower C Block is mixing with Channel 51 to produce IM products in the Lower B receive block.

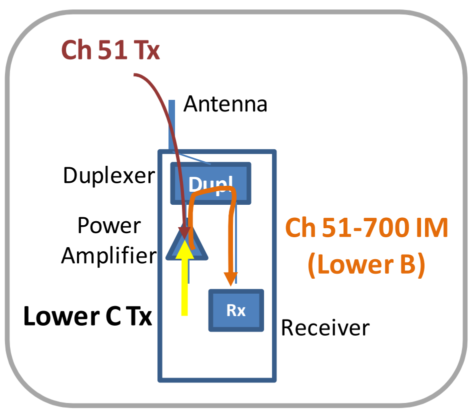

Figure 5.1: Reverse PA IM, Lower C Block and Channel 51

The third order IM products may be calculated from the difference between twice the UE transmit frequency and the Channel 51 DTV frequency. Since both signals are typically wideband signals, the IM products have a wide bandwidth as well.

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[16] 3GPP TSG WG4 Kansas City, May 2008, R4-081108, "TS36.101 Introduction of Band 15", page 1, section 2, paragraph b). Note : Motorola's contribution listed the incorrect date of April 2008 for the Kansas City meeting.

[17] The duplexer provides some loss to signals attempting to pass from the antenna through the transmit side of the duplexer to the power amplifier.

The FCC-defined spectrum block size (6+6 MHz per block) is larger than the LTE channel size defined for use in Band 17 (5+5 MHz for one block or 10+10 MHz for two blocks). This provides the operator with flexibility in placing the LTE channel within the FCC spectrum block. The optimal location of the LTE channel depends on the number of blocks owned by the operator.

Moreover, the transmission bandwidth of a 5 MHz LTE channel is 4.5 MHz, and the transmission bandwidth of a 10 MHz LTE channel is 9 MHz. The device transmission bandwidth is smaller than the channel bandwidth to provide frequency space for signal rolloff in order to comply with emissions regulations. For intermodulation calculations, the transmission bandwidth contains the significant UE power and is the frequency range of interest. A pictorial view of LTE transmission bandwidth alignment within the Lower 700 MHz paired blocks is provided in Figure 5.2, as depicted by the blue-shaded blocks.

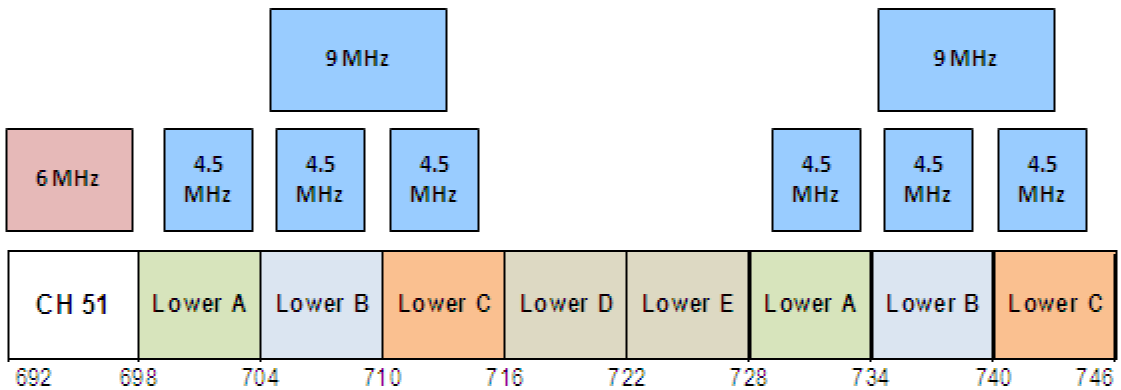


Figure 5.2: LTE Transmission Bandwidth Aligned with Lower 700 MHz Paired Blocks

When 5 MHz LTE channels are employed, the spacing between LTE channels is 5 MHz but the transmission bandwidth of the signal is 4.5 MHz. An operator deploying a 5 MHz LTE channel in the Lower B Block would center the channel within the 6 MHz block, with the lower edge at 704.5 MHz. The transmission bandwidth would begin at 704.75 MHz, which would employ half of the 1.5 MHz of unused spectrum as effective guard band at the lower channel edge.

For the Lower A Block, a 5 MHz LTE channel's transmission bandwidth would begin at 699.25 MHz to reflect the 1 MHz guard band assigned by 3GPP from 698-699 MHz[18].

If a 5 MHz channel is to be deployed in the Lower C Block, the channel's transmission bandwidth should begin at 710.25 MHz to maximize the frequency separation from the Lower D and E downlink transmissions to the LTE base station receive frequencies below 716 MHz.

[18] In 2010, 3GPP defined a 1 MHz guard band to provide additional filter room from the Lower E Block to Lower A Block.

In cases where an operator owns both the Lower B and C Blocks, the 9 MHz transmission bandwidth should begin at the lower end of the combined blocks, starting at 704.5 MHz to similarly distance the base station receive channel from the Lower D and E Block downlink transmissions.

Assuming the above LTE channel placement, Table 5.1 summarizes the intermodulation frequency ranges resulting from a mix of Channel 51 with Lower 700 MHz device transmissions.

Channel 51 DTV Tx (MHz)	Scenario	Lower 700 MHz UE Tx (MHz)	Intermodulation Products (MHz)	LTE UE Rx Block (MHz)	Impact UE Receive?	% RBs Affected
692-698	Lower A Block	A (699.25-703.75)	700.5-715.5	729.25-733.75	No	0%
692-698	Lower B Block	B (704.75-709.25)	711.5-726.5	734.75-739.25	No	0%
692-698	Lower C Block	C (710.25-714.75)	722.5-737.5	740.25-744.75	No	0%
692-698	Lower B+C Block	B+C (704.5-713.5)	711-735	734.5-743.5	0.5 MHz	5.6%

Table 5.1: Channel 51-Lower 700 MHz UE Intermodulation Products

For example, the second row in the table shows device transmissions in the Lower B Block mixing with channel 51 to produce intermodulation products from 711.5 to 726.5 MHz, depending on the number of LTE resource blocks in use within the Lower B Block. These frequencies do not fall within the Lower B Block device receive range, and therefore, would not cause interference. Indeed, none of the 5 MHz channel placements above would cause interference within the device. Therefore, a 5 MHz LTE system operating in the A, B or C Blocks would not experience reverse PA IM interference, *regardless of its proximity to a Channel 51 tower.*

The only IM combination which may affect the device's receive frequencies would be in a 10 MHz LTE channel. If the LTE system permits the device to transmit at high power in the upper end of the channel, and the Channel 51 signal is strong enough, then IM products could fall within the lowest portion of the B Block device receive block, as illustrated in Table 5.1. The affected 0.5 MHz of spectrum represents just 5.6% of the 9 MHz LTE transmission bandwidth. In other words, if reverse PA IM were to exist within a Lower B+C LTE channel, less than 6% of the downlink resource blocks might overlap with the IM products. More than 94% of the resource blocks would not overlap, leaving considerable capacity available for the device in question.

Finally, in order for intermodulation products to cause interference, the magnitude of the IM signal must be strong enough to cause interference. For interference to be created, the UE must transmit at maximum power, the DTV 51 signal must be very strong, and the device power amplifier IM response must be insufficient. Power amplifiers are designed to control intermodulation. The laboratory tests will characterize the IM response of the commercial device power amplifiers and permit calculation of the IM levels present in the Lower B receive channel as a function of DTV power.

5.2 Few DTV Stations are Near Lower B+C Operations

The last section explained the mechanism of how reverse PA IM may be generated within a device. The next step is to explore the locations of DTV 51 broadcast stations in the US. As determined in section 5.1, reverse PA IM may only be generated within a device which is transmitting in Lower C while receiving in Lower B. Therefore, reverse PA IM is only a possibility in those markets where the same licensee owns both the Lower B and C Blocks and Channel 51 delivers very strong signals to the LTE coverage area.

DTV Channel 51 is deployed at just 29 locations nationwide, and less than half of these locations fall within markets where AT&T owns both the Lower B and C Blocks. Markets where AT&T owns just one Lower 700 MHz block are automatically immune from reverse PA IM since the IM products do not overlap with the device receive frequencies.

The Channel 51 station locations are overlaid on the AT&T Lower 700 MHz spectrum position in Figure 5.3.

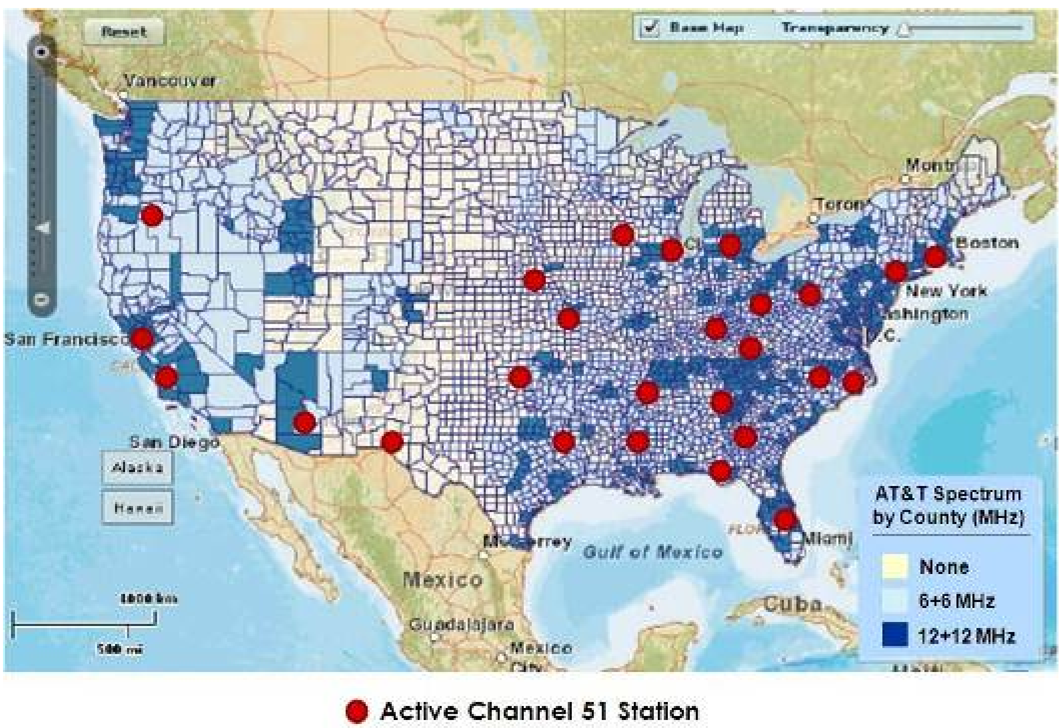


Figure 5.3: Channel 51 Stations and AT&T 700 MHz Spectrum Ownership

A DTV transmission may cover up to 60 miles, reducing the importance of building a broadcast tower in close proximity to a city to provide coverage. Thus, DTV transmitters are placed on mountaintops or on tall towers to increase their coverage range. The tall towers are generally located in remote areas to reduce visibility. The remote location of these broadcast towers significantly reduces the Channel 51 signal strength within the LTE coverage area.

Of the 29 high-power DTV 51 stations, only eight towers are located close enough to a populated area to potentially deliver a strong signal to an LTE device[19]. Of these eight locations, only three currently fall within a market where AT&T owns both the Lower B and C Blocks. The three locations are provided in Figures 5.4 through 5.6 below.

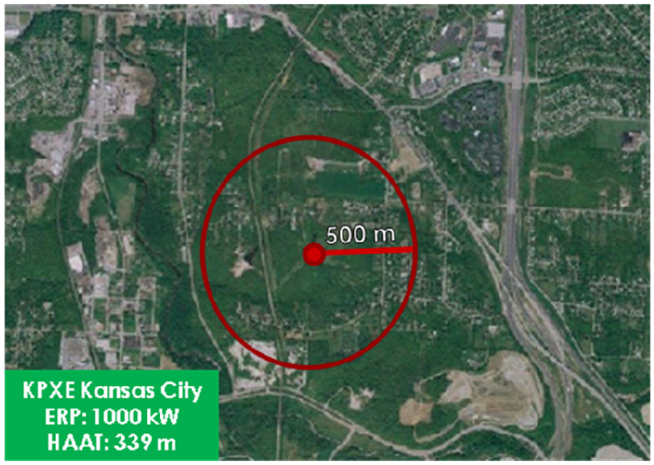


Figure 5.4: DTV 51 KPXE Kansas City

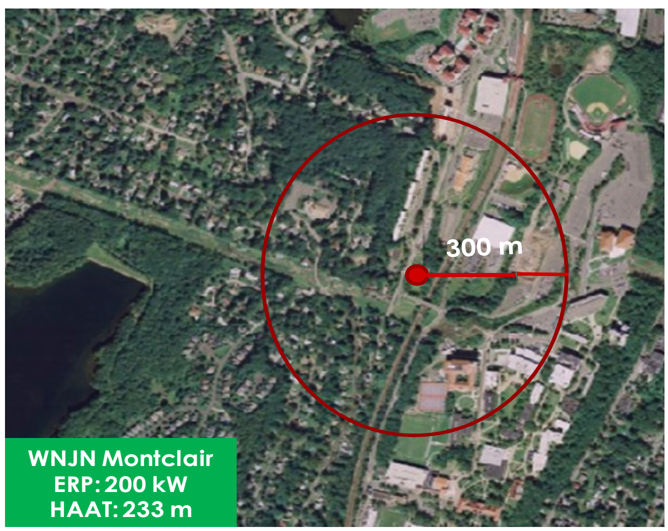


Figure 5.5: DTV 51 WNJN Montclair, NJ

[19] As demonstrated below, the Atlanta market is an excellent example of a DTV 51 station deployed in a remote location yet covering an AT&T Lower B and C market. The Atlanta DTV 51 station would never cause reverse PA IM interference to Band 12 devices.

Figure 5.6: DTV 51 WKEF Dayton, OH

The antenna mounting height at these three locations ranges from 233 meters to 351 meters. The broadcast antenna pattern focuses energy toward the horizon. For example, the antenna pattern in use at the Kansas City site is shown in Figure 5.7.

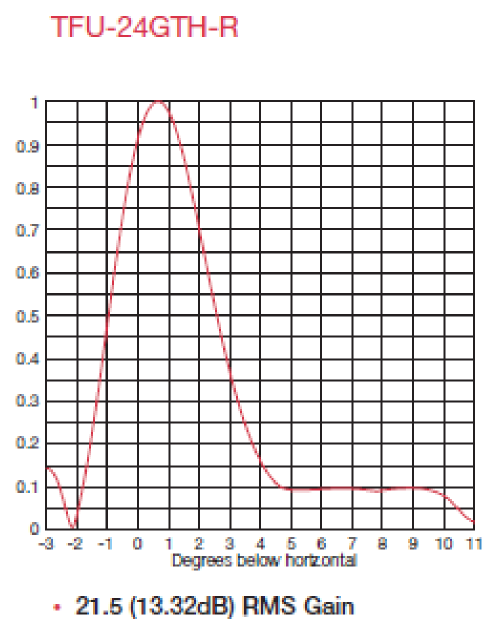


Figure 5.7: Dielectric Antenna Pattern at DTV 51 Site in Kansas City[20]

As the angle below the horizontal plane increases, the antenna gain rapidly decreases. The power radiated toward the ground is significantly lower than the maximum broadcast radiated power in the

[20] Dielectric Communications, "TV Antenna System Planning Guide", http://www.spxcomtech.com/SPX/en/our-products/broadcast/tv.asp

horizontal plane. As an example, for ground locations with a 5 degree angle to the broadcast antenna, the radiated power is 10 dB lower than the horizontal plane (10*log(0.1) = 10 dB). For an antenna mounted 331 meters above the ground, the ground location corresponding to five degrees below the horizontal is:

Ground distance = (331 meters) / (tangent(5 degrees)) = 3780 meters

Locations closer than 4 km to the DTV tower have a sharper angle to the antenna, with a correspondingly reduced ground-level power as suggested in the figure by the downward slope of the antenna pattern for angles greater than 11 degrees.

DTV ERP	1000000	1000000	W
DTV EIRP	92	92	dBm
Tower Height	339	339	m
Distance (Tower to Device)	500	3780	m
Angle to DTV Antenna	34	5	degrees
DTV Antenna Gain Reduction	-13	-10	dB
Distance (Antenna to Device)	604	3795	
Free Space Path Loss	85	101	dB
Clutter loss	10	10	dB
Ground level DTV signal	-16	-29	dBm

Table 5.2: Theoretical DTV 51 Signal near KPXE Kansas City

Table 5.2 calculates the theoretical ground-level signal for the radius of 500 meters versus 3780 meters. The broadcast antenna pattern is assumed to be reduced by 13 dB at 500 meters, which may prove to be a conservative assumption based on the antenna gain rolloff implied in Figure 5.7. Using a free space path loss formula to maximize the potential signal level, the ground-level DTV power at this distance would be approximately -16 dBm. As the distance from the site increases, the device's angle to the DTV antenna is reduced. At several kilometers distance, the device begins to enter the main lobe of the DTV antenna. The increased path loss from this greater distance more than counters the increased DTV antenna gain. Table 5.2 calculates the strongest signal which may be encountered at ground level from a full service DTV station.

In conclusion, reverse PA IM of any magnitude would not occur throughout the vast majority of the country, because the right combination of UE transmit/receive frequencies are not in use in areas where DTV signals may be strong. Currently only three locations nationwide have the conditions necessary for IM to potentially overlap a small portion of the device LTE receive frequencies, if the DTV 51 signal is strong enough and the desired LTE downlink signal is weak.

Laboratory tests were undertaken to determine the signal conditions necessary to generate reverse PA IM interference. The tests documented the third-order intermodulation performance characteristics of commercially available devices.

The field measurements of the Channel 51 transmissions in Atlanta collected ground-level signal strength throughout the market, and in the vicinity of an LPTV broadcast tower operating on channel 47.

5.3 DTV Signal Strength Measurements

The Channel 51 field measurements focused on documenting the RF environment from a live DTV transmission. The signal levels which may be encountered in a DTV market can then be compared against the measured performance of commercial devices in the laboratory.

The DTV 51 signal levels throughout Atlanta are provided in Figure 5.8. The strongest ground-level signal measured was -36 dBm when on a hilltop near the tower.

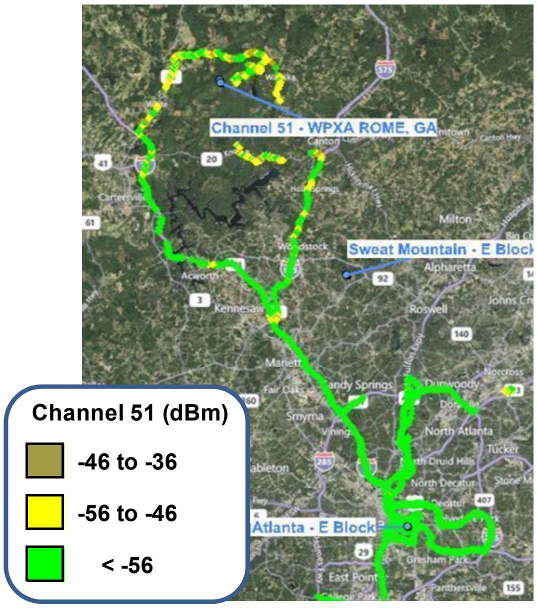


Figure 5.8: Channel 51 Signal Strength in Atlanta

As suggested by the theoretical calculations in section 5.2, DTV towers located within a city may generate a stronger ground-level signal than the -36 dBm level measured in Atlanta. As an additional reference point, Nokia presented TV signal strength measurements in a contribution to 3GPP, as reproduced in Annex A.3. The strongest signal level Nokia measured was -21 dBm at a distance of 900 meters from the tower. Notably, the signal strength measurements for points closer to the high-power broadcast tower were lower in power as a result of the reduced antenna gain toward the ground.

One adjustment to the Nokia measurement should be made: the analog broadcast transmission Nokia measured was radiating at 600 kW ERP. Therefore, to reflect a full power US DTV station, the signal level should be increased by 2.2 dB to reflect the full 1 MW. Therefore, the maximum ground-level signal becomes -18.8 dBm, relatively close to the worst-case theoretical value of -16 dBm calculated in section 5.2.

Low power television stations may transmit on Channel 51 in some areas. The RF environment around such stations was also measured, using the Channel 47 station in Norcross, Georgia as a proxy. The station is licensed to transmit at 12.5 kW. The signal levels around the LPTV tower are provided in Figure 5.9.

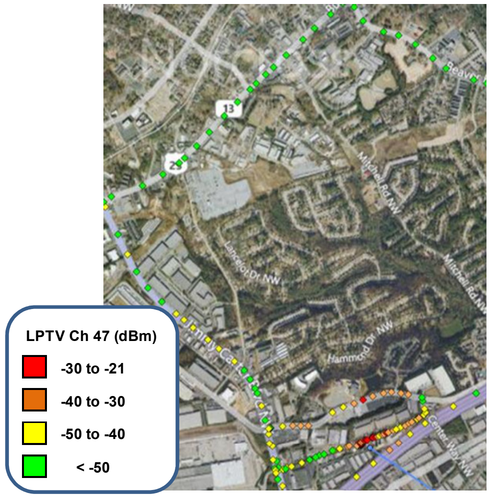


Figure 5.9: Norcross LPTV Station Coverage

The LPTV tower is closer to the ground and uses a less focused antenna than the large DTV broadcast towers. Therefore, the LPTV signal strength at ground level is expected to be relatively higher than that found near the large broadcast towers. In Atlanta, the strongest ground-level LPTV signal was measured at -21 dBm, immediately adjacent to the tower. Although the LPTV ERP was 19 dB lower than the DTV transmission, the reduced height and broader antenna pattern resulted in a similar ground-level signal strength.

Thus, the strongest ground-level Channel 51 signal which may be encountered near broadcast towers is -19 to -21 dBm, as validated by our Atlanta measurements and by the Nokia measurements in Finland. Such strong signals are encountered in a relatively small geographic area. In the case of the LPTV signal, such a strong signal was only seen within a few dozen meters of the tower base.

The laboratory tests of reverse PA IM determined whether commercially available devices are engineered to prevent harmful intermodulation from such signal levels.

5.4 Laboratory Measurements Demonstrate No Interference

Laboratory tests of reverse PA IM were conducted using AT&T commercial Band 17 devices and the test configuration described in section 3. The test approach coupled a high-power interfering signal in Channel 51 with the UE transmissions, permitting intermodulation generation. The amplitude of the Channel 51 signal was increased until measurable intermodulation was generated. Test results were captured on the spectrum analyzer.

The reverse PA IM test was a technically complex test to administer and evaluate because of the large range of signals involved. Device transmissions of 20 dBm and intermodulation signal levels near -90 dBm were measured simultaneously, requiring a measurement dynamic range of 110 dB or more.

To handle such a large dynamic range, the test configuration employed a filter which attenuated frequencies below 719 MHz. This filter reduced the magnitude of the Ch 51 interfering signal and the UE transmissions arriving at the spectrum analyzer. The filter attenuation was necessary to improve the sensitivity of the spectrum analyzer and permit measurement of the weak intermodulation signals.

With the filter in place, the spectrum analyzer screen shot for the reverse PA IM test would present an unusual appearance. The interfering DTV signal would be attenuated by the rejection filter in front of the spectrum analyzer. The UE transmission would undergo a similar attenuation as it passes through the analyzer's rejection filter. All signals below 719 MHz would undergo an average of 60 dB of attenuation, greatly reducing their magnitude relative to signals above 719 MHz. Any intermodulation products that are generated in the device would not be attenuated by the rejection filter, since the products would fall in frequencies higher than 719 MHz. Interpreting the analyzer screen shot correctly requires a translation of the signal levels on the screen to the actual signal levels at the device.

This interpretation process is illustrated in Figures 5.10 and 5.11 for the case of a one resource block LTE UE transmission at maximum power, with no interfering signals present. Within the 10 MHz LTE channel, the UE transmission appears as the strongest signal near the upper edge of the LTE channel (with 180 kHz bandwidth). The next peak to the left of the device transmission is the local oscillator. The image frequency is also visible further to the left. To the right of the device transmission (above 716 MHz), a cross-modulation product of the UE transmission with the LO is visible, followed by a cross-modulation of the UE Tx with the image frequency.

The signal levels from the device perspective are stronger than the levels shown on the spectrum analyzer because the analyzer's view is affected by the filtering of signals below 719 MHz. The view of all signal levels from the device's perspective may be derived by adjusting the amplitudes of the signals visible on the spectrum analyzer by the attenuation levels of the respective filters and the insertion loss of the test setup. The adjusted view for this LTE signal is provided in Figure 5.11 below, reconstructed and plotted in Excel to account for the filtering.

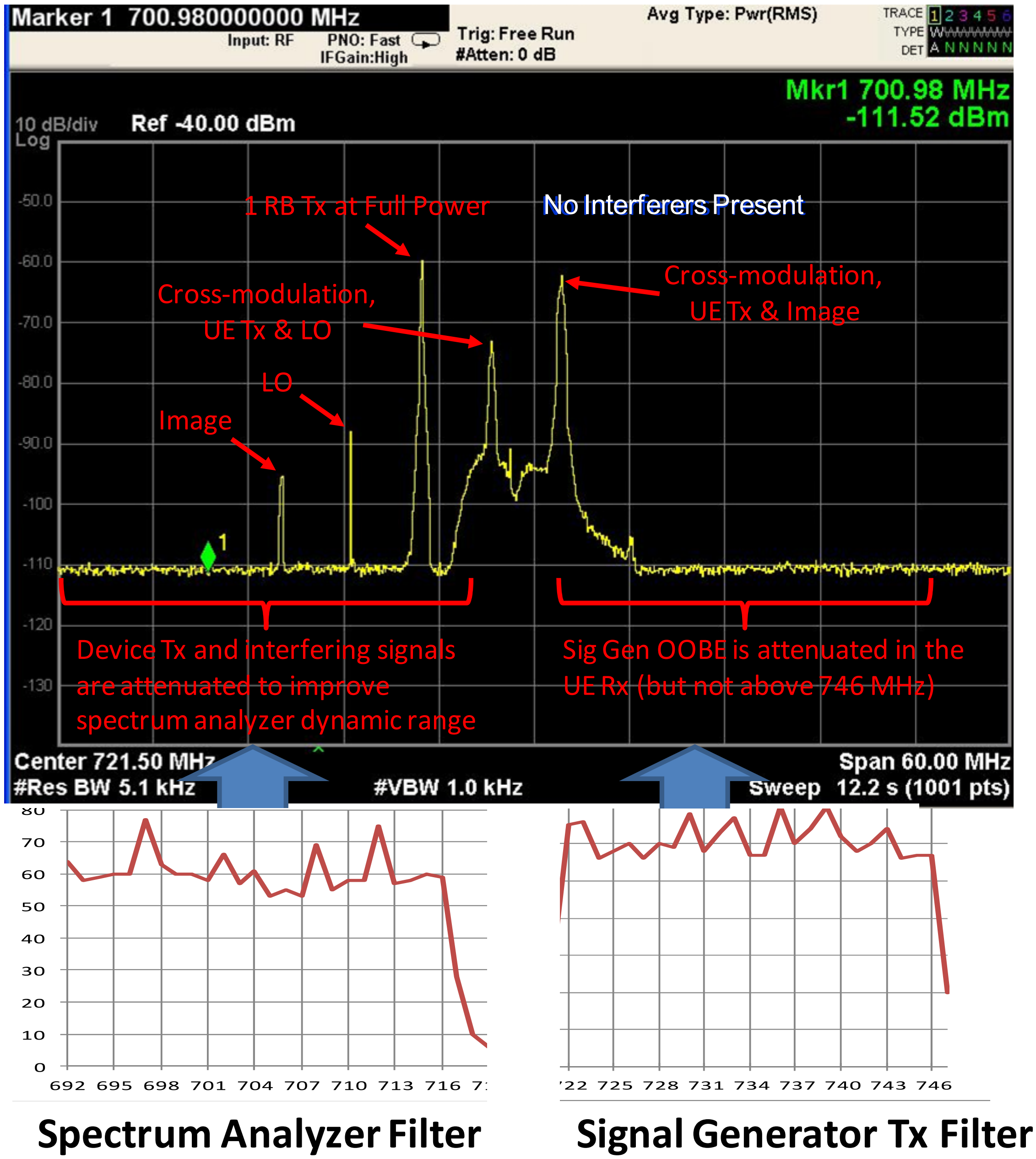


Figure 5.10: Spectrum Analyzer Screen Shot Interpretation

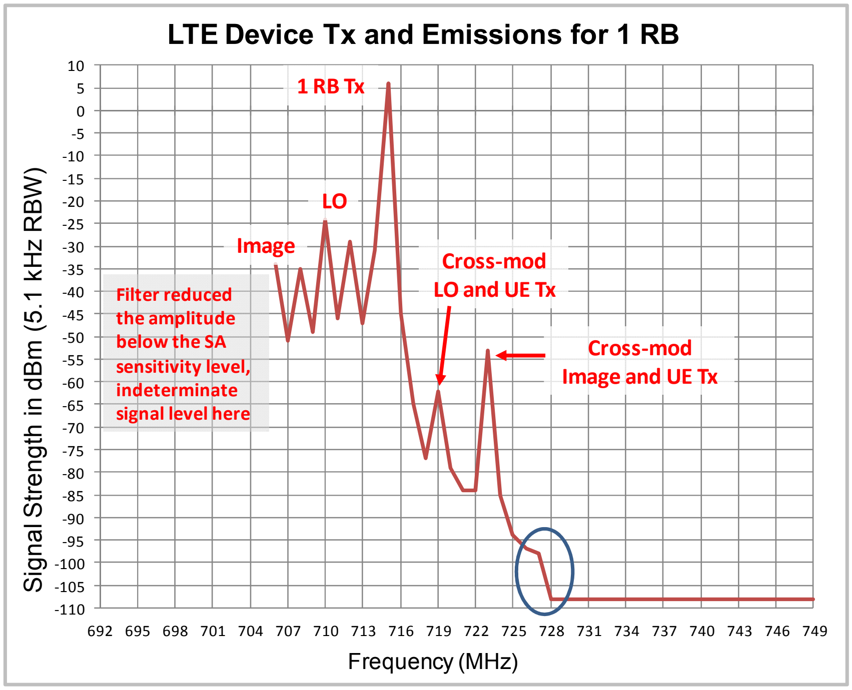


Figure 5.11: Adjusted Analyzer Screen Shot from the Device Perspective (5.1 kHz RBW)

As expected, Figure 5.11 shows the UE transmission as the strongest signal. The sharp dropoff from 727 MHz to 728 MHz and above (blue circle) suggests that the Band 17 transmit filter is providing a sharp rolloff in this area to protect device reception from the device transmissions.

The reverse PA IM test results are shown in Figures 5.12 through 5.14. Figure 5.12 reproduces the view in Figure 5.10 with no interferers present, as a reference for comparison with the following two figures.

Figure 5.13 includes a high power 6 MHz interferer centered in DTV Channel 51. The UE transmission at the upper end of the LTE channel produced IM products which slightly overlap with the LTE receive frequencies, as derived in the earlier table of theoretical IM products.

The Channel 51 amplitude was increased significantly in order to measure an intermodulation product; the laboratory-emulated DTV 51 signal levels would be impossible to encounter in a DTV market. Nevertheless, in order to demonstrate the mechanism of intermodulation, we applied this greatly increased interferer signal level to the test setup in order to create measurable IM products. Figure 5.13 shows the reverse PA IM test performance for the Band 17 device. The test results include any assistance provided by the Band 17 device RF transmit filter.

Note that the test approach placed the LTE channel in the center of the Lower B+C blocks, which slightly altered the intermodulation frequency range relative to the analysis in section 5.1.

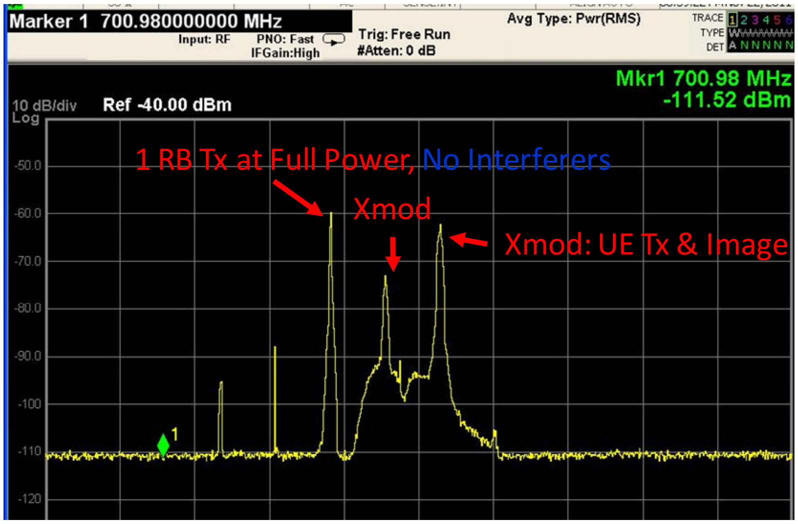


Figure 5.12: UE Transmit of 1 RB with No Interferers

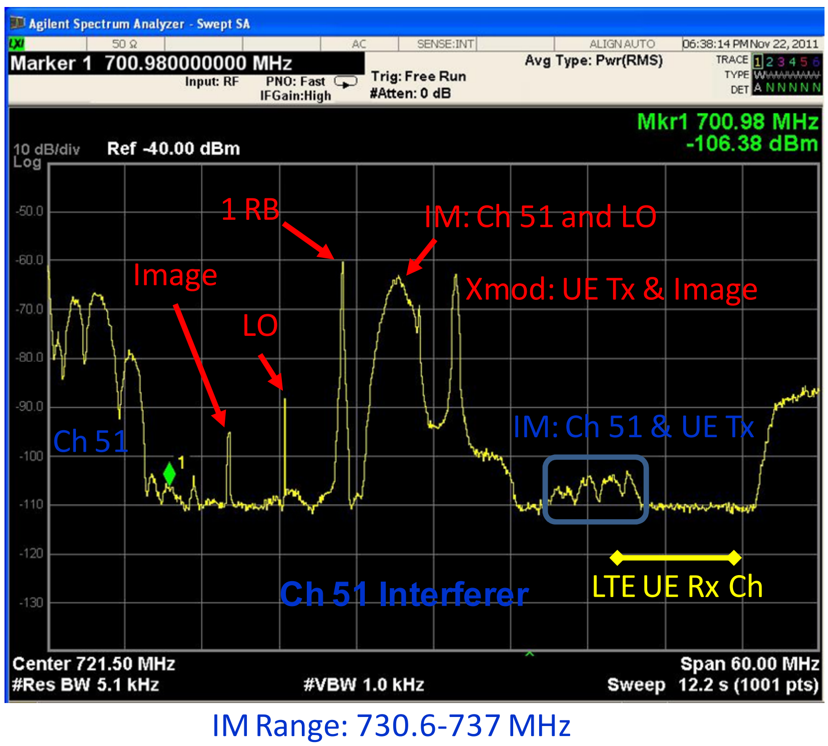


Figure 5.13: UE Transmit of 1 RB with DTV Ch 51 Interferer

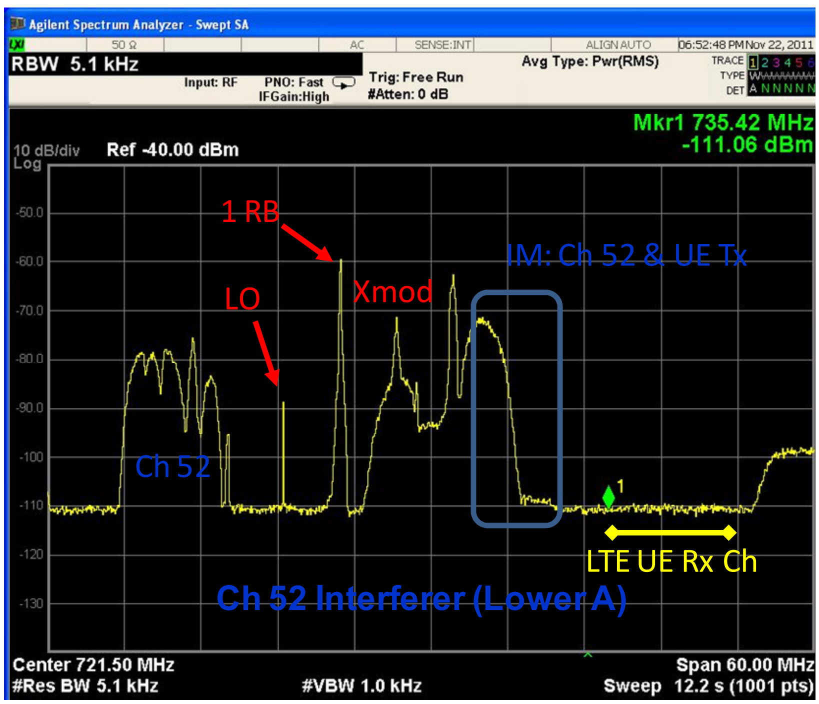
The Band 17 device is more than capable of handling the strongest possible Channel 51 signals that may be encountered near a broadcast tower. To create a measurable block error rate (BLER), the DTV power at the UE antenna port was increased to more than +18 dBm, an impossibly strong signal to encounter in a market.

To demonstrate that Band Class 12 devices would operate normally in the Lower B and C Blocks, we must examine Band 12 device performance under the same conditions. With respect to reverse PA

IM, the main difference between a Band 17 device and a Band 12 device would be the transmit filter attenuation in the direction of the Channel 51 interferer. The Band 17 transmit filter provides a gradual rolloff below the transmit band (below 704 MHz). The Band 12 transmit filter would begin rolling off at 699 MHz, a difference of 5 MHz.

For typical surface acoustic wave (SAW) filter performance, we estimate the Band 17 transmit filter attenuation within the DTV 51 channel to be on the order of 5 to 10 dB. In order to emulate the IM performance which would result if the AT&T devices used a Band 12 transmit filter, we moved the interfering signal to Channel 52, the Lower A Block. The Band 17 filter provides less attenuation to frequencies in the Lower A Block than in Channel 51. By placing the interfering signal in the Lower A Block, the interference is immediately adjacent to the Band 17 transmit filter passband. This arrangement emulates the case where the Channel 51 interference is directly adjacent to the Band 12 transmit filter passband; a similar attenuation level by the transmit filter would be seen.

Figure 5.14 shows the interferer moved upward 6 MHz into the Lower A Block to emulate the case where a Band 12 device RF filter was used with an interferer in DTV 51.



IM Range: 724.6-731 MHz

Figure 5.14: UE Transmit of 1 RB with DTV Ch 52 Interferer

With the interferer in Lower A, the resulting intermodulation products [(2 x Lower C UE Tx) - (Lower A interferer)] move lower in frequency, into the Lower D and E Blocks. The IM products falling within the Lower D and E Blocks (716-728 MHz) undergo less attenuation by the device transmit filter relative to the IM products falling within the device receive band (734-746 MHz). The intermodulation product amplitudes must be adjusted by the device RF transmit filter curve illustrated in Figure 5.15.

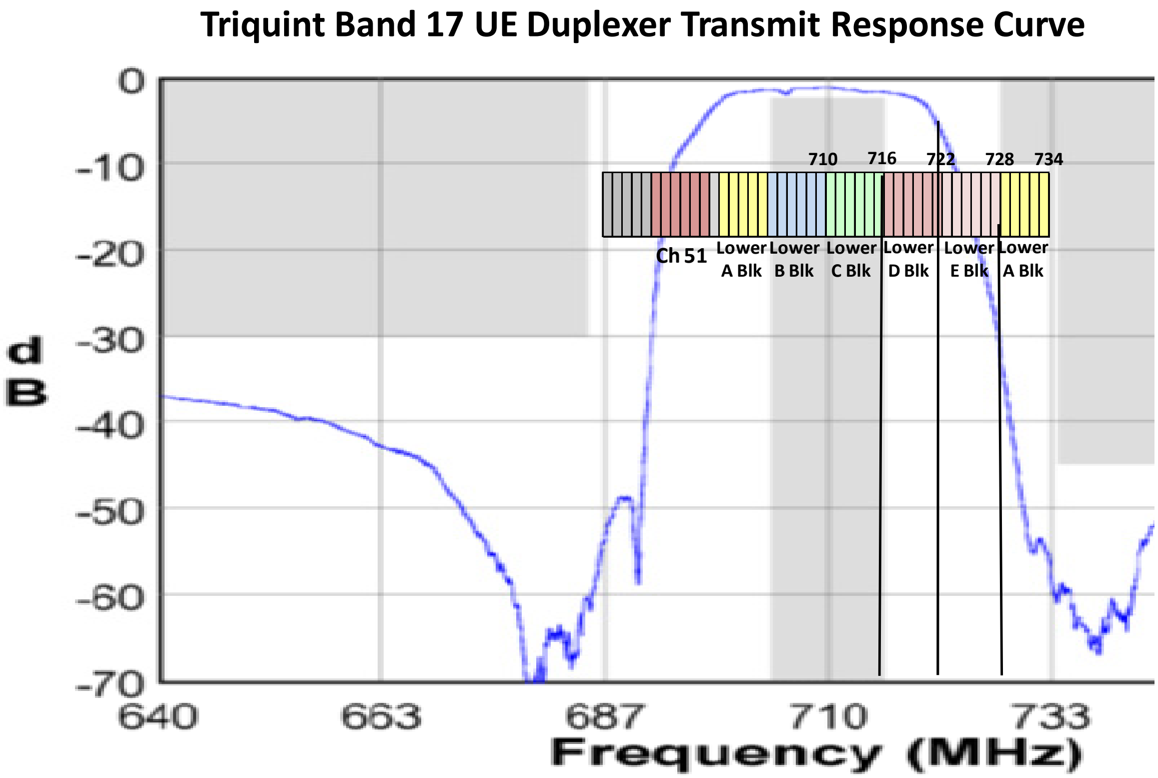


Figure 5.15: Triquint Band 17 Transmit Filter Response

The interferer signal strength was set to be 9 dB lower in this test. Since the test generated similar IM levels as the Ch 51 test, the delta between Band 17 and Band 12 reverse PA IM performance is 9 dB. This matches expectations based on the Triquint filter curve in Figure 5.15, which provides 5 to 10 dB of attenuation within Channel 51. While it is not known whether the AT&T devices make use of this or another duplexer model, the filter shape is expected to be representative of typical filter technology for this band.

With a delta in measured results of 9 dB, the Band 17 transmit filter does not significantly reduce the amplitude of the Channel 51 interferer. Instead, the IM product strength is dominated by the UE transmit power. This observation makes intuitive sense because the UE transmit power carries twice the weight in the amplitude calculation as compared with the Channel 51 signal level. As seen from the Triquint filter response, the Band 17 rejection of Channel 51 is relatively modest; the power amplifier intermodulation response must provide the lion's share of the protection from IM generation.

A Band Class 12 device employed in a similar situation would not produce significantly different intermodulation product levels. The power amplifier third order intercept point is of much greater impact in eliminating intermodulation concerns than the RF transmit filter. The power amplifier performance is not dependent on the band class of the device. Band Class 12 and Band Class 17 devices would perform similarly in terms of the PA response.

A full analysis of the reverse PA IM measurements is provided in Table 5.3 for several scenarios. The calculated OIP3 for the power amplifier is 36 dBm for each of four test scenarios.

The first section in Table 5.3 derives the power level of the DTV interfering signal at the device antenna port. The first two rows provide the lower and upper edge frequency of the interfering signal. The row labeled “c” is the interfering signal strength as measured at the spectrum analyzer, within a 5.1 kHz resolution bandwidth. Row “d” provides the spectrum analyzer filter loss across the interferer frequencies. Row “e” contains the signal level at the input to the spectrum analyzer filter. Row “f” is the difference in loss from the generator-to-analyzer path versus the generator-to-UE path, which is 2 dB. Finally, row “h” converts the measurement bandwidth to 6 MHz to provide the interferer signal strength at the UE antenna port.

The second section in Table 5.3 converts the measured UE transmission power at the spectrum analyzer to the reference point of the UE power amplifier. Row “i” indicates the number of resource blocks assigned to the test scenario. The first two test columns used one resource block at maximum power. The last two columns used five resource blocks at maximum power. Next, row “j” denotes the relative position of the resource blocks within the LTE channel. The first two columns place the RB transmission at an offset of 49, which is the highest frequency assignment within the channel and the worst case position for IM generation. The third column places the five resource blocks at the uppermost edge of the LTE channel, again the worst case placement in terms of IM generation. The fourth column moves the five resource blocks to an offset of 40, adjacent to the assignment in the third column.

As noted in the theoretical calculations, the RB assignment of 40 does not produce a theoretical overlap with the LTE receive blocks. Even though the intermodulation products were visible on the spectrum analyzer screen, the IM did not overlap with the LTE receive channel. The laboratory test with the offset of 40 did not result in block errors in the downlink channel, confirming the lack of interference for UE transmit assignments below the uppermost edge of the LTE channel.

Rows “k” and “l” provide the UE transmission frequencies. Row “m” contains the measured UE transmission power at the spectrum analyzer within a 5.1 kHz resolution bandwidth. Row “n” lists the insertion loss of the spectrum analyzer filter, cabling, and coupler between the spectrum analyzer and the UE antenna port. Row “q” provides the UE transmit signal at the antenna port, after adjustments for the spectrum analyzer filter attenuation and test setup losses. Row “s” is the UE Tx power level at the PA.

The third section of Table 5.3 is the measured IM response. The intermodulation products appear in or near the device receive band, and are not attenuated by the spectrum analyzer filter. Rows “t” and “u” provide the lower and upper frequency range of the generated IM products. Note that the IM bandwidth is the sum of the DTV interferer bandwidth plus twice the UE transmission bandwidth. Thus, the UE transmission with five resource blocks produces a wider IM product bandwidth than the 1 RB transmission.

Row “w” is the measured IM strength as depicted at the spectrum analyzer. Row “z” provides the IM power level within one resource block, as referred to the UE antenna port.

The last section in Table 5.3 provides the theoretical calculations for reverse PA IM using the same power levels as in the tests. This section reverse engineers the third order output intercept point (OIP3) for the power amplifier of the device under test. The first step is to determine the duplexer loss in row "ab" from the Triquint filter curve. A greater attenuation is attributed to Channel 51 than to the Lower A Block to reflect the Band 17 transmit filter response in each block. Row "ae" calculates the OIP3 from the UE transmit power and DTV interfering signal strengths. The OIP3 was determined to be 36 dBm. In row "af", the Triquint transmit filter response is applied to the generated IM frequencies. Row "ah" contains the final IM power level at the device receiver falling within one resource block (180 kHz).

The values in the yellow-shaded rows may be compared within a column. The first yellow row provides the measured IM response. The second yellow row is the theoretically derived IM level; the case with the interferer in Lower A is determined after adjustments for the duplexer transmit filter curve. Note that in the case of the interferer in the Lower A Block (second column), the device duplexer transmit filter provides approximately 20 dB less attenuation to the IM products falling within Lower E versus the IM products on frequencies above 728 MHz. Because of this reduced filter attenuation, the observed intermodulation signal is stronger. This result is expected given the relative positions of the interferer, the UE transmission, and the generated intermodulation product. When the measured IM level within the Lower E Block is adjusted to reflect an IM power level that would result for higher frequencies within the receiver pass band, undergoing greater duplex filter attenuation, the IM levels are shown to be similar to the Band 17 test with the interferer in Channel 51. These results are valid because both Band 12 and Band 17 transmit filters would provide at least 50 dB of attenuation to the device receive frequencies.

From these tests, we calculate the Band 17 device transmit filter rejection of Channel 51 to provide at most 9 dB of additional rejection relative to a Band Class 12 filter. This delta is the approximate difference observed between the Ch 51 and Lower A interferer tests. The 9 dB difference also matches the attenuation level within Channel 51 indicated by the Triquint transmit filter curve as provided in Figure 5.15, further indication that the Triquint transmit filter is representative of the AT&T Band 17 filter.

DTV Interferer Measurements

DTV Interferer Placement	Ch 51	Lwr A	Ch 51	Ch 51	
Interferer Start Frequency (MHz)	692	698	692	692	a
Interferer End Frequency (MHz)	698	704	698	698	b
Interferer Signal Strength at Analyzer (dBm)	-70	-80	-70	-70	c
RF Filter Attenuation (dB)	60	61	60	60	d
Interferer Signal Strength at Filter (dBm)	-10	-19	-10	-10	e = c + d
Delta in Cable/connector losses to UE (dB)	2	2	2	2	f
Spectrum Analyzer RBW (kHz)	5.1	5.1	5.1	5.1	g
Interferer Power in 6 MHz at Ant Port (dBm)	18.7	9.7	18.7	18.7	h = e - f + 10*log(6000/g)

LTE UE Tx Measurements

UE RBs Transmitted	1	1	5	5	i
UE RB Offset	49	49	45	40	j
UE Tx Start Frequency (MHz)	714.32	714.32	713.6	712.7	k
UE Tx End Frequency (MHz)	714.5	714.5	714.5	713.6	l
UE Measured Signal at analyzer (dBm)	-60	-60	-65	-64	m
Insertion loss, UE to Signal Analyzer (dB)	6	6	6	6	n
UE Tx Signal Strength (dBm)	-54	-54	-59	-58	o = m + n
RF Filter Attenuation (dB)	59	59	58	57	p
Total UE Tx power at ant port (dBm)	20.5	20.5	21.5	21.5	q = o + p + 10*log(180 or 900*i/g)
Duplexer Tx insertion loss (dB)	2	2	2	2	r
Total UE Tx power at PA (dBm)	22.5	22.5	23.5	23.5	s = q + r

Measured IM Response

IM Frequency Range Start (MHz)	730.6	724.6	729.2	727.4	t = 2*k - b
IM Frequency Range Stop (MHz)	737	731	737	735.2	u = 2*l - a
IM bandwidth (MHz)	6.4	6.4	7.8	7.8	v = u - t
IM Measured Amplitude in 5.1 kHz RBW (dBm)	-105	-85	-105	-105	w
Insertion Loss, UE to Signal Analyzer (dB)	6	6	6	6	x
IM Amplitude at UE (w/ SA RBW) (dB)	-99	-79	-99	-99	y = w + x
IM Power (in 180 kHz) (dBm)	-83.5	-63.5	-83.5	-83.5	z = y + 10*log(180/g)

Theoretical IM Analysis

DTV Power at UE Antenna Port (dBm)	18.7	9.7	18.7	18.7	aa = h
UE Duplexer Loss (dB)	10	2	10	10	ab
DTV Power at UE Power Amplifier (dBm)	8.7	7.7	8.7	8.7	ac = aa - ab
UE Tx Power (dBm)	22.5	22.5	23.5	23.5	ad = s
OIP3 (dBm)	36	36	36	36	ae
UE Duplexer Tx-Rx Isolation (dB)	50	29	50	50	af
Total IM Power (dBm)	-68.3	-48.3	-66.4	-66.4	ag = 2*ad + ac - 2*ae - af
IM Power (180 kHz) (dBm)	-83.8	-63.8	-82.7	-82.7	ah = ag + 10*log(180/(v*1000))

Table 5.3: Measured Intermodulation Products Compared with Theoretical Analysis

The test results provided in Table 5.3 were generated with unrealistically high DTV interfering signals. It is physically impossible to encounter a +9 to +18 dBm DTV broadcast signal outside of a laboratory.

To translate these measurements to an operational environment, the strongest ground-level DTV 51 signal encountered near a broadcast tower would be in the vicinity of -21 dBm as described above. Furthermore, device certification reports for Lower 700 MHz LTE devices show an antenna gain of -5 dBi, lowering the impact of DTV interference. The duplexer attenuation is assumed to be 2 dB, which is the worst case of no benefit from the Band 12 device transmit filter toward Channel 51. Applying these numbers to the calculation of IM product strength yields the results shown in Table 5.4.

COMMERCIAL REVERSE PA IM SCENARIO

DTV Power at UE Antenna (dBm)	-21.0	a
UE Antenna Gain (dBi)	-5.0	b
UE Duplexer Loss (dB)	2	c
DTV Power at UE Power Amplifier (dBm)	-28.0	d = a + b - c
UE Tx Power at PA (dBm)	23.5	e
OIP3 (dBm)	36	f
UE Duplexer Tx-Rx Isolation (dB)	50	g
Total Power in Full IM Product BW (dBm)	-103.0	h = 2*e + d - 2*f - g
IM Power (1 RB, 180 kHz) (dBm)	-118	i = h + 10*log(180/IM bw)
LTE UE Rx sensitivity for 180 kHz (dBm)	-111	j
IM Signal Below RefSense (dB)	**7**	k = j - i

Table 5.4: Commercial Reverse PA IM for Band 12

With the performance demonstrated by AT&T's commercial LTE devices and making proper adjustments to represent Band 12 filter performance, Table 5.4 demonstrates that even in the worst-case RF conditions measured in a DTV market, any IM products would fall 7 dB or more below the receiver sensitivity. No interference would result to Lower B and C Block device reception, even when the device is operating at the receiver sensitivity (weakest LTE signal).

The lab and field measurements conclusively demonstrate that reverse PA IM from Channel 51 broadcast transmissions will not interfere with device reception, even under the worst case conditions. The intermodulation rejection of the device is more than sufficient to eliminate any intermodulation interference concerns. The Band 17 RF filter does not play a necessary role in managing Channel 51 intermodulation interference. The device power amplifier provides more than sufficient third-order response suppression to handle the Channel 51 environment. The AT&T devices may employ Band 12 filters with no risk of interference to Lower B and C Block device reception. 3GPP Band Class 17 is not needed to protect devices from reverse PA IM interference.

5.5 Reverse PA IM Results Submitted to FCC November 2011

The reverse PA IM test results submitted to the FCC on November 28, 2011 differ slightly from the above analysis. In November 2011, we made working assumptions regarding the Band 17 duplexer performance to derive the signal levels at the power amplifier. In subsequent work, we assessed and refined the analysis with actual Band 17 duplexer characteristics per publicly available information. This work provided a more accurate view of signal levels at the power amplifier module, which in turn revised the derived OIP3. The technical information submitted to the FCC in November 2011 is shown in Figure 5.16.

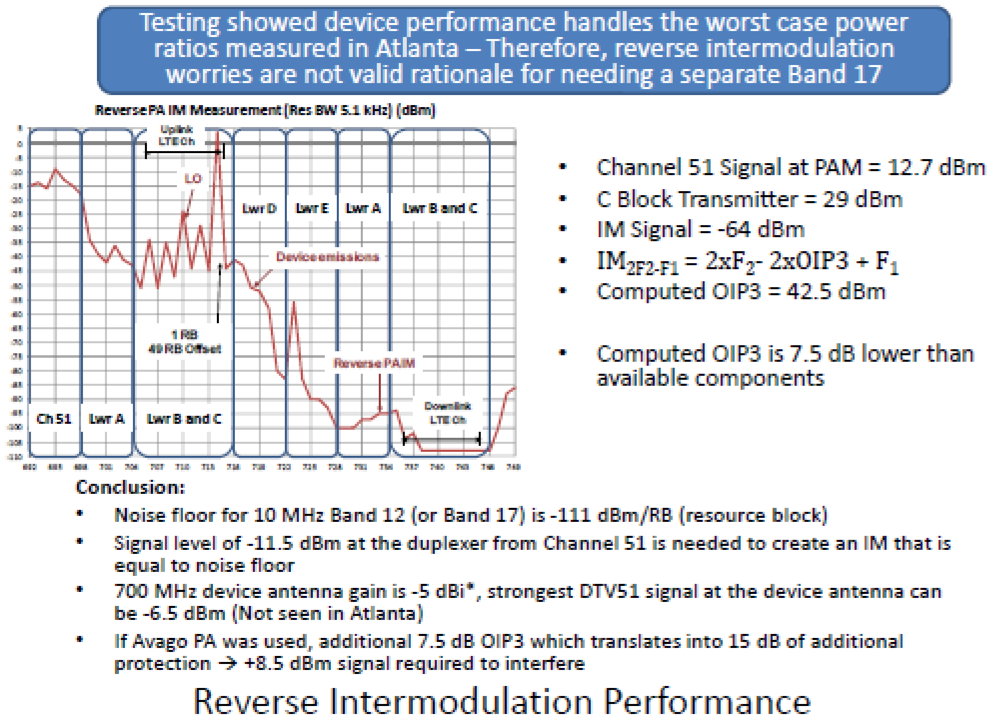


Figure 5.16: Reverse PA IM Technical Information Submitted to FCC on November 28, 2011

The changes in approach are highlighted in Table 5.5 below, providing a side-by-side view of the deltas. The first difference is the device transmit power. In the November 2011 presentation, we assumed the worst case of a 27 dBm device transmit power at the antenna port, which translated to a 29 dBm power level at the power amplifier. In the revised view herein, we derived the antenna port power from the spectrum analyzer plots – a lower value, which reduced the calculated OIP3. This lower value concurs with the conducted power measurements as reported in the device compliance tests, as submitted to the FCC by the certifying laboratories.

The second difference is the device duplexer transmit-to-receive isolation. We assumed 55 dB in November, but revised this number downward to 50 dB based on the Triquint filter curve and the manufacturer's performance specifications. This adjustment provides a more conservative view of IM performance; filters with 55 dB of isolation would further reduce IM levels and increase the available margin.

Thus, in November we stated that a signal level of -6.5 dBm was required to generate IM equal to the device reference sensitivity. In the revised view using the actual device transmit power and the revised OIP3 figure, the value becomes -13.5 dBm. Since the strongest measured DTV signal in the field was -19 to -21 dBm, there is still considerable excess margin to ensure that IM interference would not be experienced in a commercial system. Any IM generated within a device containing a Band 12 filter would fall at least 7 dB below the receiver sensitivity, under the worst-case conditions.

		March 2012	November 2011
DTV Power	At UE Antenna (dBm)	-13.5	-6.5
	UE Antenna Gain (dBi)	-5.0	-5.0
	At Duplexer (dBm)	-18.5	-11.5
	UE Duplexer/Cable Loss for B12 Filter (dB)	2	2
	At UE Power Amplifier (dBm)	-20.5	-13.5
UE Tx Power	At UE Antenna Port (dBm)	21.5	27
	UE Duplexer/Cable Losses (dB)	2	2
	UE Tx Power at PA (dBm)	23.5	29
IM Analysis	OIP3 (dBm)	36	42.5
	UE Duplexer Tx-Rx Isolation (dB)	50	55
	Total Power in Full IM Product BW (dBm)	-95.5	-95.5
	IM Power (1 RB, 180 kHz) (dBm)	-111.0	-111.0
	LTE UE Rx sensitivity for 180 kHz (dBm)	-111.0	-111.0
	IM Signal Below RefSense (dB)	0.0	0.0

Table 5.5: Comparison of Reverse PA IM Analyses (November to March)

Recalling the observation of LTE system design thresholds in section 4, the LTE operator should be targeting a ground-level signal of at least -80 dBm to ensure adequate coverage within buildings and cars. The desired LTE downlink signal would thus be at least 10 dB stronger than the LTE signal level used in the laboratory tests. The available margin in an LTE system would thus increase to 17 dB.

Stating this another way, because the LTE operators target stronger street-level signals than the minimum the device may receive, the math in Table 5.5 should be adjusted accordingly. The DTV 51 signal which would be required to generate IM equal to the LTE design threshold would be -3.5 dBm, an exceedingly strong signal level which would not be encountered in a market.

5.6 Simple Workaround Eliminates IM Interference for 3GPP Reference Receivers

The preceding test results and analyses conclusively demonstrated that Band 12 devices would perform normally in the Lower B and C Blocks when in the vicinity of Channel 51 broadcast stations.

If any operator harbors lingering reservations regarding the use of Band Class 12 devices near DTV 51 towers, then other measures are available to provide full protection to any Band 12 device. *The simplest measure is one that would fully protect all Band Class 12 devices, would cost nothing to implement, and would have no significant impact to performance.*

This simple workaround is to configure the one or two sites closest to the DTV 51 tower as 5 MHz LTE sites. The AT&T base stations would support one 5 MHz channel in the Lower B Block and one 5 MHz channel in the Lower C Block. Since a total of 10 MHz of LTE capacity is provided, the sector capacity is virtually the same. No reverse PA IM interference would exist because the devices would only transmit and receive in the same block – and not be allocated cross-over assignments with the device transmitting in one block and receiving in the other. Under this approach, any IM generated would not cause interference to the device.

Since this approach would impact three to six LTE sites nationwide out of an approximate 20,000 site deployment (<0.03% of all sites), the effort of configuring these few sites as two 5 MHz channels instead of one 10 MHz channel is minimal.

AT&T already plans to support a mix of 5 MHz and 10 MHz channels in its LTE system. AT&T's base stations and devices are capable of supporting either 5 or 10 MHz LTE channels because of AT&T's varying spectrum ownership around the country. In markets like Atlanta where AT&T owns both the Lower B and C Blocks, AT&T is deploying the 10 MHz LTE channel. In other markets where AT&T owns just one of the two blocks, AT&T would deploy a 5 MHz LTE channel.

This simple workaround would provide full protection to all Band 12 devices, including hypothetical 3GPP reference receivers, regardless of the LTE system design near the DTV tower. Band Class 17 is not need to prevent reverse PA IM.

6. Conclusions

The proponents of Band Class 17 claimed that Lower E Block and Channel 51 broadcast transmissions may interfere with LTE device reception in the Lower B and C Blocks if a Band Class 12 RF filter were used instead of the narrower Band Class 17 filter.

The first interference claim was that blocking to a Band Class 12 device receiver would occur when near Lower E Block broadcast towers. In order for such receiver blocking to occur, the Lower B and C Block LTE signal must be weak, the Lower E Block signal must be strong, and the device receiver must be incapable of handling the difference in power between the Lower E Block signal and the Lower B/C Block LTE signal.

The field testing in Atlanta documented the RF signal strength near Lower E Block broadcast towers transmitting at the maximum ERP of 50 kW. Laboratory tests of commercial AT&T devices validated the LTE receiver performance in the presence of strong nearby signals and a weak Lower B/C Block LTE signal. The laboratory tests employed procedures which effectively removed the Band Class 17 RF filter from the analysis in order to determine the performance of just the receiver. The laboratory test results showed that the LTE receiver could operate normally in the RF environment measured in Atlanta – even in the worst case environment of the Fayetteville Lower E Block site where the AT&T LTE coverage produced weak signals. The commercial AT&T devices performed 13 dB better than required for operation in the worst case RF environment measured in Atlanta. This 13 dB margin is more than sufficient to cover a wide range of device component variation or Lower E Block configurations.

The field measurements also revealed that a hypothetical 3GPP reference receiver operating in the Lower B and C Blocks would encounter similar signal levels when near an adjacent LTE base station as when operating near a Lower E Block broadcast tower. Indeed, with tens of thousands of LTE base stations operating in nearby spectrum nationwide, such systems would pose a considerably greater risk to the hypothetical reference receiver than would a few hundred Lower E Block broadcast towers. Commercial devices are therefore designed to perform better than the 3GPP minimum specifications in order to provide normal operation near neighboring Lower A and Upper C Block LTE base stations. The narrower Band Class 17 RF filter is not needed to prevent Lower B and C Block receiver blocking near Lower E Block broadcast towers.

The second interference claim was that a Band Class 12 device might experience interference from reverse power amplifier intermodulation produced when near DTV Channel 51 broadcast stations. In order for this interference mechanism to exist, a “perfect storm” of conditions must simultaneously transpire:

- The LTE device must be transmitting at high power in a few frequencies at the upper end of the Lower C Block[21].

[21] Device transmissions which span many frequencies must spread their power over a wider bandwidth, which reduces the power per frequency. The lower power density reduces the amplitude of any intermodulation generated from DTV 51 and device transmissions. Therefore, a device with maximum power applied to a small number of frequencies is the worst case assumption for intermodulation interference calculations.

- The LTE device must be receiving a weak signal at the lower end of the Lower B Block[22].
- The DTV Channel 51 signal level must be very strong – at power levels rarely encountered in a market.
- The LTE device power amplifier's intermodulation suppression must be considerably worse than that of the AT&T commercial devices measured in the laboratory.

In other words, in operational LTE markets employing Band Class 12 devices with power amplifiers similar to those in AT&T's commercial devices, reverse power amplifier intermodulation would never be experienced. And if reverse power amplifier intermodulation interference were ever to be encountered by hypothetical commercial devices performing well below current commercial devices, a multitude of operator-configurable solutions would be available, each one capable of eliminating such potential interference at no cost to the operator. The narrower Band Class 17 RF filter is not needed to protect Lower B and C Block device reception near DTV Channel 51 towers.

In conclusion, the laboratory and field tests demonstrated that Band Class 17 is not needed for technical reasons. A Band Class 12 device would provide normal performance in the presence of Lower E Block and Channel 51 broadcast towers, and there would be no interference threat to Lower B and C Block device reception.

[22] Only the lowest portion of the Lower B Block could mathematically overlap with any potential intermodulation from strong DTV 51 signals. The remainder of the Lower B+C LTE channel would not overlap and would remain unaffected, regardless of the strength of the DTV 51 signal.

Annex A: Path Loss Measurements

The Lower E Block signal strength at ground level is similar to the levels measured from cellular towers. Systems deployed within the same spectrum band will present ground-level signals much stronger than that captured by the 3GPP blocking specifications. To avoid widespread interruptions in service within a city, the UEs in the marketplace must greatly exceed the minimum blocking specifications.

Annex A provides test measurement results from several systems to illustrate the similarity of ground-level signals for cellular and broadcast towers. Section A.1 reproduces Motorola measurements submitted to the FCC in 2010 illustrating how cellular signals may greatly exceed the 3GPP blocking specifications. Section A.2 provides additional stationary measurements for a cellular site in Raleigh, NC. Section A.3 summarizes a Nokia contribution to 3GPP which provided measurements of digital television systems in Finland.

The three sections in Annex A demonstrate the similar range of strong signals from the different systems. The broadcast systems place antennas on tall structures and use high power to maximize coverage range. The broadcast antenna focuses energy toward the horizon, reducing the ground-level signal strength in the vicinity near the tower. As a result, the “hot spots” are no hotter than those found near cellular towers, which mount antennas closer to the ground and tilt the beam downward to reduce the energy toward the horizon. UEs designed to work properly within a typical LTE system would not suffer adverse performance when near a Lower E Block broadcast tower.

A.1. Motorola Field Measurements

Motorola submitted three sets of interference measurements to the FCC in WT Docket 06-150[23]. Motorola submitted the measurements to demonstrate that cellular-like systems employ many sites and achieve strong ground-level signals. Motorola's concern was the cellular signal strength might pose an interference risk to 700 MHz Public Safety devices when in weak PS coverage areas.

Motorola's characterization of cellular signal strength is helpful in providing context for the interference claims from the Lower E Block. LTE UEs operating in the Lower B or C Blocks must be built to withstand signal levels in nearby LTE base station transmit blocks, such as Lower A or Upper C. The signal levels in these nearby spectrum blocks may approach the levels illustrated by Motorola below. From Motorola's measurements, an LTE UE should be designed to handle interfering signals in nearby blocks of -10 dBm or higher to avoid receiver blocking.

The first Motorola field measurement is for a storage facility in San Diego, CA. The strongest ground-level signal was recorded as -10.3 dBm. The Motorola summary is reproduced in Figure A.1.

Figure A.1: Motorola Cellular Measurements in San Diego, CA

[23] Motorola ex parte presentation, FCC WT Docket 06-150, PS Docket 06-129, Steve Sharkey, April 12, 2010.

Motorola's third bullet in Figure A.1 includes an explanatory note in red font. Similar notes appear in Motorola's slides reproduced in Figures A.2 and A.3 below. Motorola's note explains that some locations in operational networks may experience less path loss than the minimum coupling level assumed by 3GPP. Motorola references the 3GPP document TR 36.942 "Radio Frequency (RF) System Scenarios", which defines the assumptions used in developing the LTE specifications[24]. In section 4.5.1 of TR 36.942, Table 4.4 defines the minimum coupling loss between a base station and a device as 70 dB.

In Figures A.1, A.2, and A.3, Motorola contrasts 3GPP's 70 dB coupling loss with the path loss measured by Motorola in cellular field tests to drive home the point that ground-level signals from LTE base stations can be stronger than the level assumed by 3GPP. Motorola's testing illustrates the importance of robust commercial device design to handle such strong signals in nearby, in-band spectrum blocks. To ensure that commercial devices do not experience blocking interference near other operators' towers, the devices must be designed with a sufficient dynamic range to receive weak desired signals in the presence of strong interfering signals.

The second Motorola field measurement is for a cellular tower in Anne Arundel County, Maryland. The peak signal level on a nearby bridge was recorded at -16.2 dBm. The Motorola summary of the test results is provided in Figure A.2.

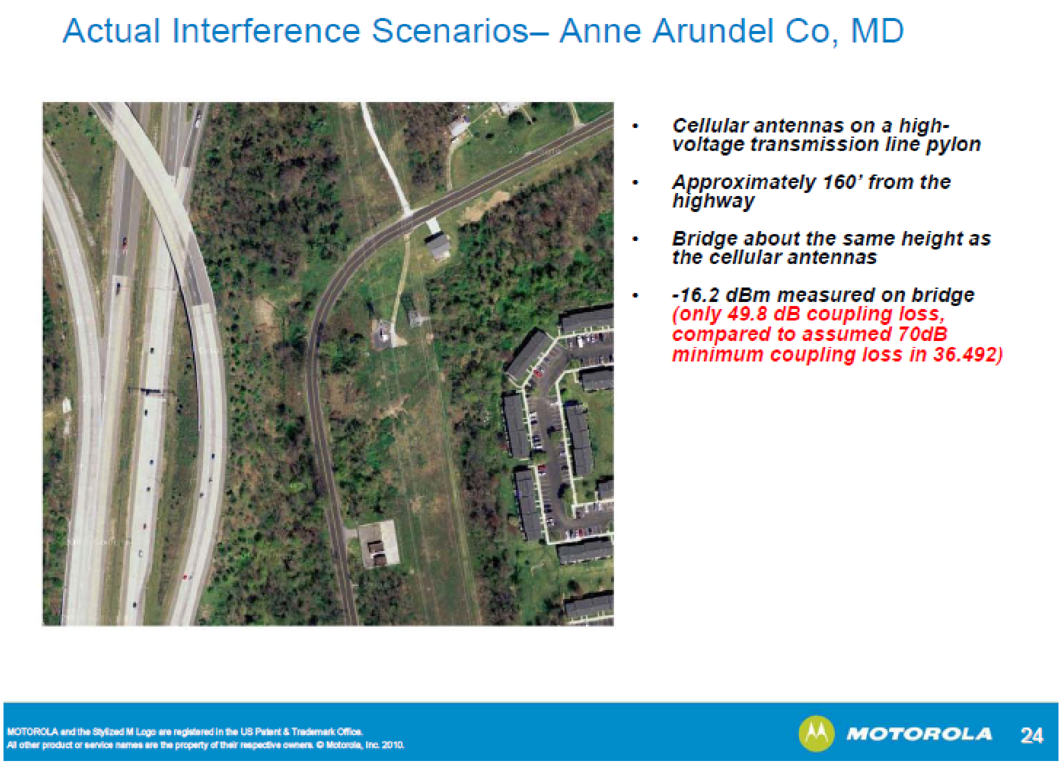


Figure A.2: Motorola Cellular Measurements in Anne Arundel County, MD

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[24] Motorola's slides incorrectly reference 36.492, a typographical error since 36.492 is not an assigned number in the 3GPP specification series.

The third Motorola field measurement is for the Las Vegas Convention Center. Motorola noted that several operators across the street from the convention center attempt to penetration the dense construction material with high-power base stations. The signal level on the street outside of the convention center is measured to be as high as -12.1 dBm. The Motorola summary of the Las Vegas test results is provided in Figure A.3.

Figure A.3: Motorola Cellular Measurements near Las Vegas Convention Center

Thus, Motorola's field test measurements demonstrate that cellular-like signals near where UEs would often expect to operate may be exposed to signal levels in the range of -10 to -16 dBm. Such strong signals are considerably stronger than the 3GPP reference receiver blocking specification of -56 dBm. The Motorola measurements are also stronger than the expected ground-level signals from Lower E Block broadcast towers.

In the case of the convention center, other operators have likely deployed base stations in the same vicinity since all have the same goal of covering the convention center. Thus, the UEs would work well outside of the convention center because the RF environment resembles that of ACS Case 2 – a strong desired signal overcoming a very strong interfering signal.

The first two Motorola test cases, however, are more isolated situations of a one-operator tower. The neighboring systems may not employ towers in the immediate vicinity. UEs serving on these more distant towers must be capable of handling the strong interfering signals of -10 to -16 dBm to avoid blocking when near the other operator's tower.

A.2. Raleigh, NC Field Measurements

A typical cell site in Raleigh, NC was selected to measure the path loss and building penetration experienced for a system operating in the 850 MHz band. The 850 MHz band is sufficiently close to 700 MHz to provide a reasonable approximation of performance. The base station antenna mounting height was 50 meters. The test location was 600 meters away from the tower. The aerial view of the tower and test location is provided in Figure A.4.

Figure A.4: Field Measurements in Raleigh, NC

The field measurements recorded the signal strength at each location around and within the library. The library is a single story facility of brick and glass construction. Figure A.5 provides the signal levels for a representative LTE system around and within the building. The signal levels were derived using the measured path loss for the existing 2G system and calculating the ground-level signal strength from an LTE downlink EIRP of 60 dBm.

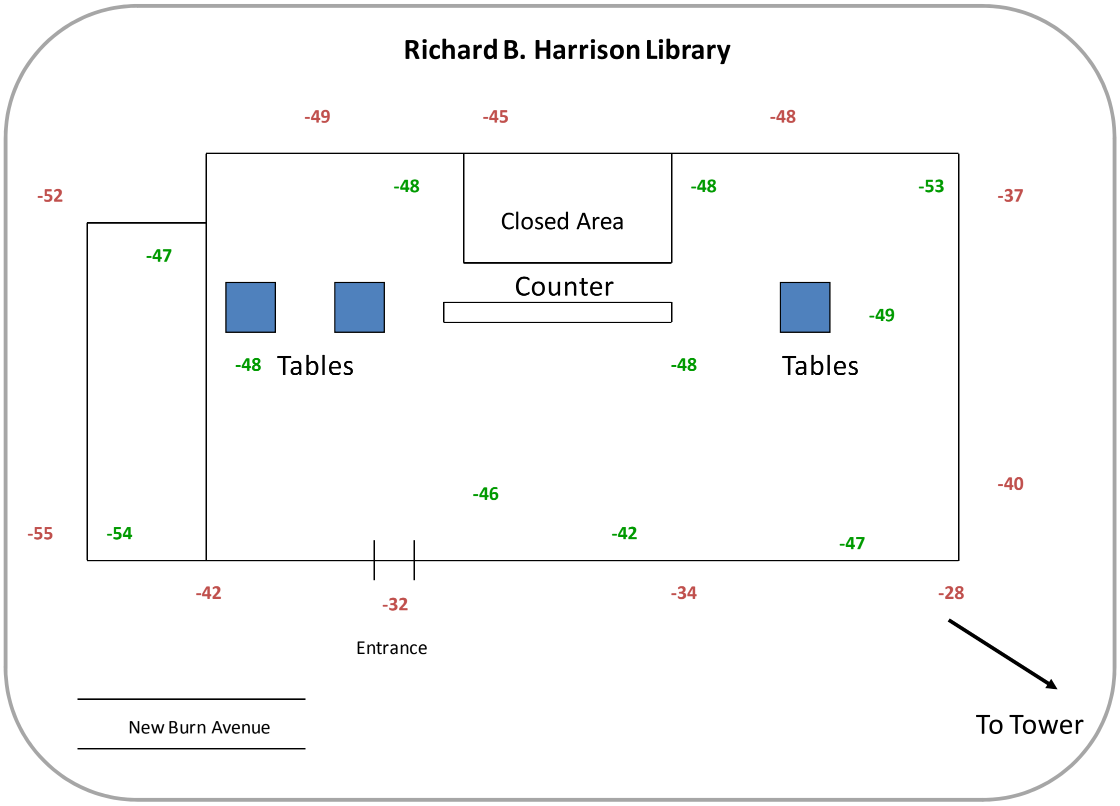

Figure A.5: Signal Levels at Library in Raleigh, NC

Even with 600 meters of separation, the signal strength on the ground within line-of-sight of the tower range from -28 to -42 dBm. The building penetration loss, derived from the difference between the external and internal signals, is on the order of 15 dB. This delta is important - wireless operators design systems to work within buildings, and such a practice requires a correspondingly stronger street-level signal in order to penetrate the buildings. The stronger street-level signal provides greater immunity to strong signals in nearby spectrum blocks.

A.3. Nokia Broadcast Television Measurements

In 2010, Nokia submitted field measurements[25] for analog and digital television stations in Finland. The measurements were undertaken to determine the likely maximum signal level resulting from a high-site, high-power broadcast transmitter, and a lower-power transmitter representative of a Lower E Block service.

The broadcast antennas were mounted 326 meters above ground level. The analog TV station transmitted with an ERP of 600 kW. The digital station transmitted with 50 kW ERP. Nokia's measurement route is provided below.

Figure A.6: Nokia Measurement Route

Nokia's measurement results are provided in the below table. The RTT column captures measurements from a repeater, and were not the main focus of the testing. The test setup used a 2.1 dBi gain antenna to capture stationary measurements of signal strength as a function of distance from the transmitter. The analog transmitter frequency close to 700 MHz was channel 52; the other two analog signals were considerably lower in frequency and not directly comparable to a 698 MHz broadcaster. The peak signal captured for this 600 kW transmitter was -21 dBm at a distance of 900 meters, with most

[25] 3GPP TSG RAN WG4 #56 Band 12 Ad Hoc, Chicago, R4-B12AH-007, "TV transmission power at UE antenna port", Nokia, September 29-30, 2010.

measurements much lower than this level. The measurements closer in to the tower were actually lower in power, illustrating the impact of the reduced antenna gain toward the ground versus toward the horizon.

The 50 kW digital transmitter measurements peaked at -23 dBm and also reduced in amplitude considerably with distance. Channels 44 and 46 were both close to 700 MHz to be representative of a digital broadcast transmission similar to the US Lower E Block.

						Calibrated Measured Power [dBm]						
				Distance [km]		Analogue			Digital			RTT
Number	Place	Lat	Long	Tx1	Tx2	24	35	52	32	44	46	27
1	Latokaski	60 10 42.4	24 38 49.8	0.4	15.6	-26	-23	-26	-29	-25	-36	-83
2	Latokaski	60 10 36.0	24 39 17.5	0.9	15.2	-20	-25	-21	-27	-23	-41	-79
3	Latokaski	60 10 39.0	24 40 01.3	1.5	14.6	-27	-38	-26	-25	-27	-23	-77
4	Puolarmet	60 10 25.9	24 42 06.0	3.5	12.8	-33	-23	-28	-26	-27	-29	-75
5	Kuitinmäk	60 09 59.3	24 44 21.4	5.6	11.1	-43	-40	-38	-36	-39	-39	-69
6	Tapiontori	60 10 36.0	24 48 25.2	9.3	7.2	-43	-46	-50	-48	-47	-53	-61
7	Otaniemi	60 11 20.4	24 50 02.0	10.9	5.3	-46	-47	-47	-49	-53	-46	-64
8	Lauttasaa	60 09 48.6	24 52 46.6	13.5	5.2	-34	-37	-41	-32	-36	-37	-46
9	Kaisaniem	60 09 15.2	24 57 15.2	17.6	5.8	-40	-41	-38	-44	-44	-45	-69
10	Stadion	60 11 04.1	24 55 35.8	15.9	2.3	-53	-61	-63	-59	-62	-60	-50
11	Stadion	60 11 21.1	24 56 00.9	16.3	1.8	-61	-61	-57	-63	-63	-62	-35
12	Pasila	60 12 09.9	24 55 11.5	15.8	0.3	-50	-49	-41	-45	-52	-49	-29

Table A.1: Nokia Field Measurements of Analog and Digital Television

As demonstrated by the field measurements in Table A.1, the ground-level signal strength from high-power broadcast towers is lower than that measured within typical cellular systems. The measurements provided in sections A.1 and A.2 were equal to or greater than the broadcast signal strength. Therefore, a UE designed to operate within a typical LTE system would not experience adverse performance within the coverage area of a neighboring 50 kW broadcast service as may be found in the Lower E Block.